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REDESIGN OF WATERJET BARRIER FLOTATION SYSTEM

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AND THE MMS

APPROXIMATELY

1.0 INTRODUCTION

Currently available booms are unable to contain oil at sites where currents exceed about 0.5 m/s (1 knot) and/or the sea conditions exceed about sea state 3. There is a need for a means to contain oil in higher currents and sea states. In recognition of this need, a series of projects has been undertaken by Environment Canada to develop a high pressure waterjet barrier for oilspill containment. Laboratory tests (Meikle, 1983; Meikle et al, 1985; Hebron, 1985; Phillips et al, 1987; Laperriere et al, 1987; Comfort and Punt, 1989) and trial field deployments (Laperriere, 1985; Punt, 1990) have been conducted. These tests have shown that the waterjet barrier concept has promise as a tool for oilspill containment in high currents.

However, experience has shown that the performance of the waterjet barrier is currently limited by its flotation system and a redesign is required. This project has been undertaken to improve the flotation system and to produce a prototype waterjet barrier system. This report documents the design and development of the revised waterjet barrier.

2.0 CONCEPT DESIGN

2.1 Review of Past Performance

A meeting was held with the client and the available movies and photographs from all previous field deployments were analyzed. This provided an understanding of the design requirements and the past performance of the waterjet barrier.

A prototype unit was first deployed at Cultus Lake, B.C. in 1984. Problems were experienced with the flotation system and a redesigned flotation system was produced using boat fenders to support a platform on which the nozzles were mounted. See Figure 2.1.

The barrier was then tested in the Mackenzie River at Norman Wells, NWT (Meikle et al, 1985; Laperriere, 1985). Problems were experienced again with the floatation system. The barrier was difficult to manoeuvre as the floats had large drag and a lack of stability, especially when the fender-type floats became oriented at 90° to the current.

Further efforts were made to improve the flotation system and circular disc-shaped floats were produced. See Figure 2.2. These floats had lower drag and greater stability than the fender-type floats (Hebron, 1985).

A field deployment was next conducted in 1989 in the St. Lawrence River at Prescott, Ontario (Punt, 1990). The barrier was deployed in a "V" configuration with an umbilical line back to the mother ship (CCGS SIMCOE). See Figure 2.3 and Plate 2.1. Disc-shaped floats were used to support the arms of the barrier while fender-type floats were used to support the umbilical line. (Fender-type floats were used as insufficient disc floats were available for the whole barrier.)

A number of problems were encountered with the waterjet barrier during these tests. The barrier could not be held in place when it was deployed alongside the ship. Rather, it was swept aft by currents created around the bow of the ship. Also, the arms could not be held at an angle conducive to containing oil (which is about 120°). The arms began to close together (as the barrier was swept aft) and oil escaped at the apex of the barrier.

Efforts were made to resolve this problem by positioning the barrier ahead of the ship. A longer umbilical hose was installed and supported with "fender-type" floats. Unfortunately, the drag of this barrier was too great to allow it to be moved ahead of the ship. This problem was compounded by the fact that the current in the test area had increased from 0.5 m/s (for the initial broadside deployment) to about 0.75 m/s on the day that these tests were conducted.

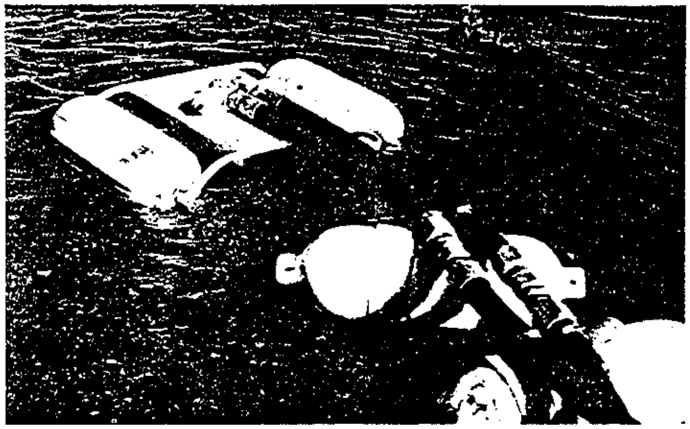


Figure 2.1
Fender-type Float (after Laperriere 1985)

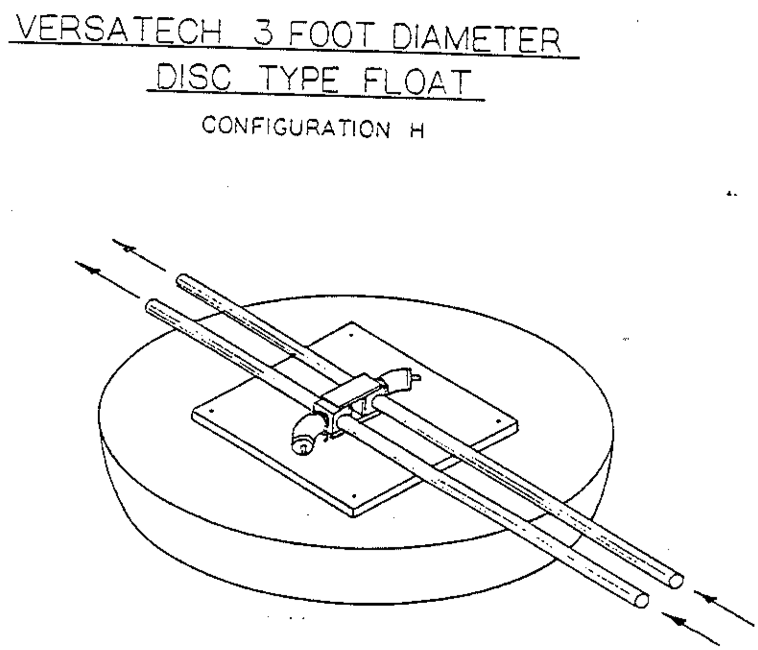


Figure 2.2
Disc-type Float (after Hebron, 1985)

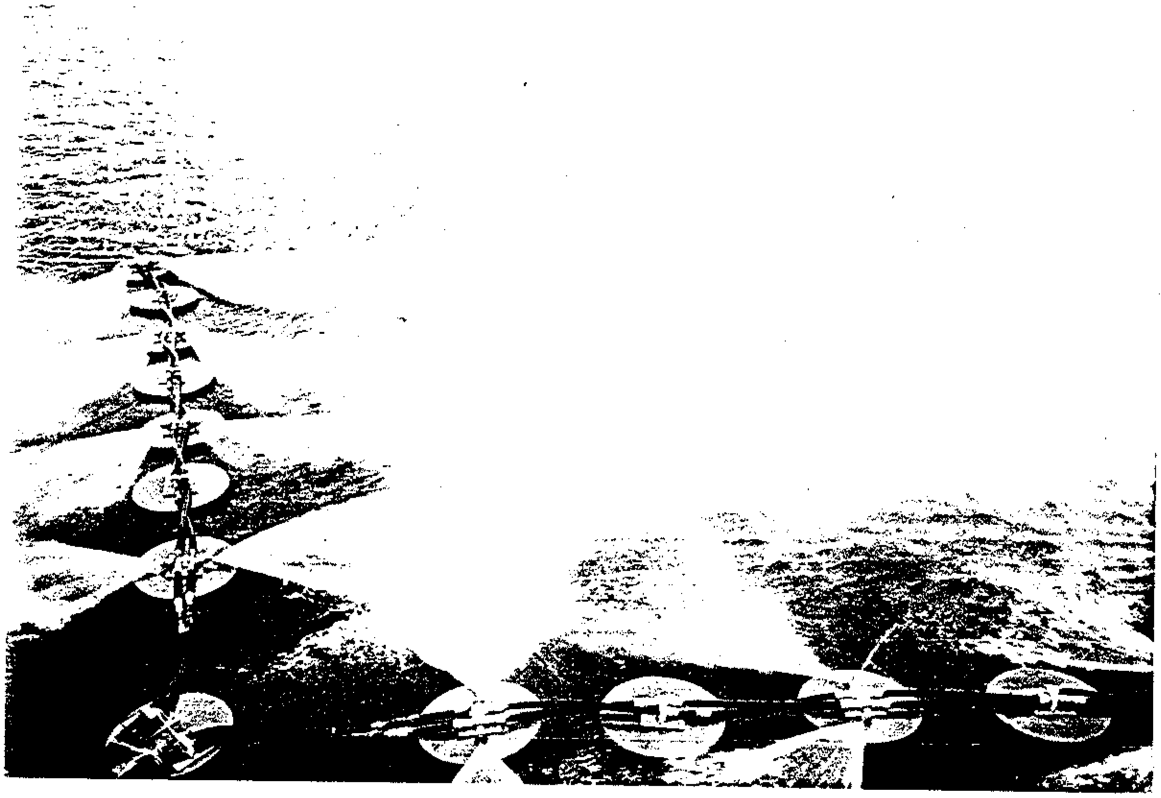


Plate 2.1

Existing Waterjet Barrier System Deployed in St. Lawrence River
(Photo courtesy of M. Punt)

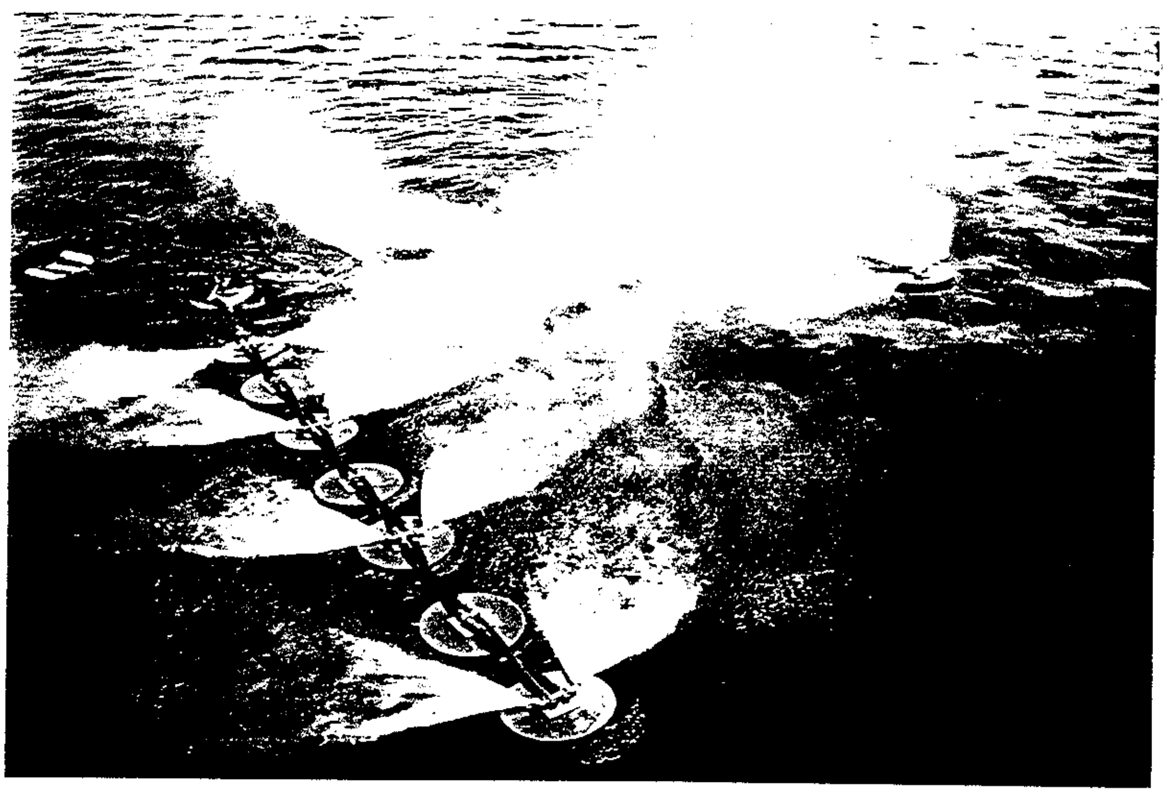


Plate 2.2

Flipped Disc Float During Trials at Prescott, Ontario
(Photo courtesy of M. Punt)

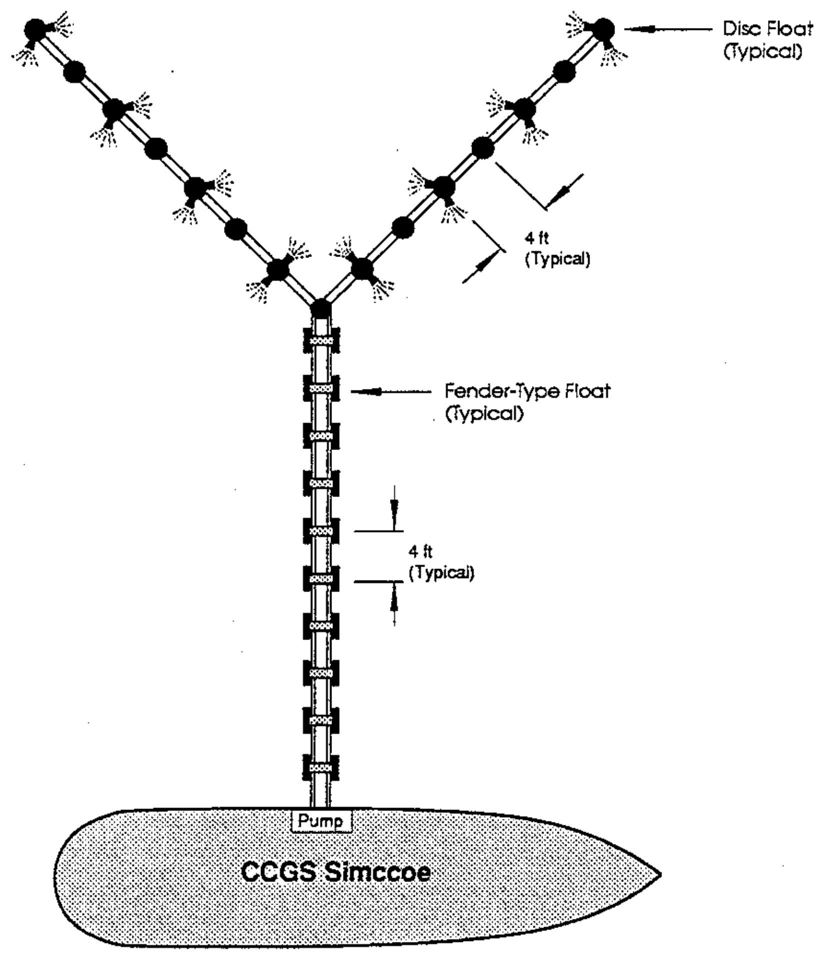


Figure 2.3: Waterjet Barrier Configuration Tested at Prescott, Ont.

Other problems were experienced during these trials. A number of the disc-type floats flipped over during operation of the waterjet barrier. See Plate 2.2. Also, the nozzle-mounting system did not allow them to be elevated sufficiently above the water. Previous tests have shown that the performance of the nozzles was optimized when they were mounted 15 to 30 cm above the water surface (Phillips et al, 1987). During the Prescott trials, the nozzles were less than 15 cm above the water surface.

The main conclusions of this review were that:

(a) The existing waterjet barrier is too flexible. During some previous deployments, particularly those at Cultus Lake, B.C., the barrier was observed to coil up in the water. A more rigid barrier is required.

(b) The disc floats have too much drag and insufficient stability orthogonal to the barrier.

(c) The flotation system should keep the nozzles 20 cm (8 in) above the water surface and it should keep the jet horizontal. It is not necessary, however, for the floats to follow the waves well but excessive pitching motions are to be avoided.

(d) The present arrangement in which the hoses are twisted back and forth contributed to the overturning of the floats which has occurred during past deployments. It was decided to keep the hoses straight for the redesigned system.

(e) The redesigned system should be portable and capable of being deployed from a mother ship, or from shore, without the aid of additional vessels. Furthermore, it should break down into relatively small components which can be easily stored, transported and assembled.

2.2 Alternatives Considered and Selected Concept

Several alternatives were considered for improving the existing waterjet barrier. The design changes fall into two general categories, as follows:

(a) flotation system improvements,

(b) general arrangement improvements.

Figure 2.4 illustrates the concept selected for the redesigned waterjet barrier.

Flotation system improvements were made by:

(a) using an "airfoil-type" float which is able to "weathervane" in the current, and,

(b) reducing the number of floats by spacing them at 2.4 m (8 ft) centres (rather than at 1.2 m (4 ft) centres which is the case for the present design).

Several alternative float designs were evaluated. Numerical analyses and prototype testing were carried out to select a float design which has low drag and which is able to "weathervane" in a current of at least 0.3 m/s (0.5 knots). This work, and the selected float design, are detailed in Section 3.

Alternative **general arrangements** for the waterjet barrier were considered as another means of improving its performance. Efforts were made to develop a design which is more rigid while still allowing the barrier to move due to wave action.

It was decided to attach the hoses to external supports between the floats. This has the advantages that it decreases the flexibility of the barrier and that it allows the floats to be spaced further apart (which reduces drag by reducing blockage effects). Consideration was given to using a pipe as both a support member and as a delivery tube for the water. This will reduce the overall weight of the barrier. However, the weight saving is small in comparison to the total weight supported by each float. On the negative side, the "integral support/water delivery tube" approach is more complex and costly, as the joint at the end of each arm is difficult to produce (as it must have some flexibility to respond to wave action). Consequently, it was decided to use an external support for the discharge hoses. This also has the advantage that it maximizes the usage of the parts of the existing waterjet barrier, which will minimize the costs for the prototype.

The external supports will be pinned together so that the barrier arm is azimuthally rigid but still free to move in the vertical direction. See Figure 2.4.

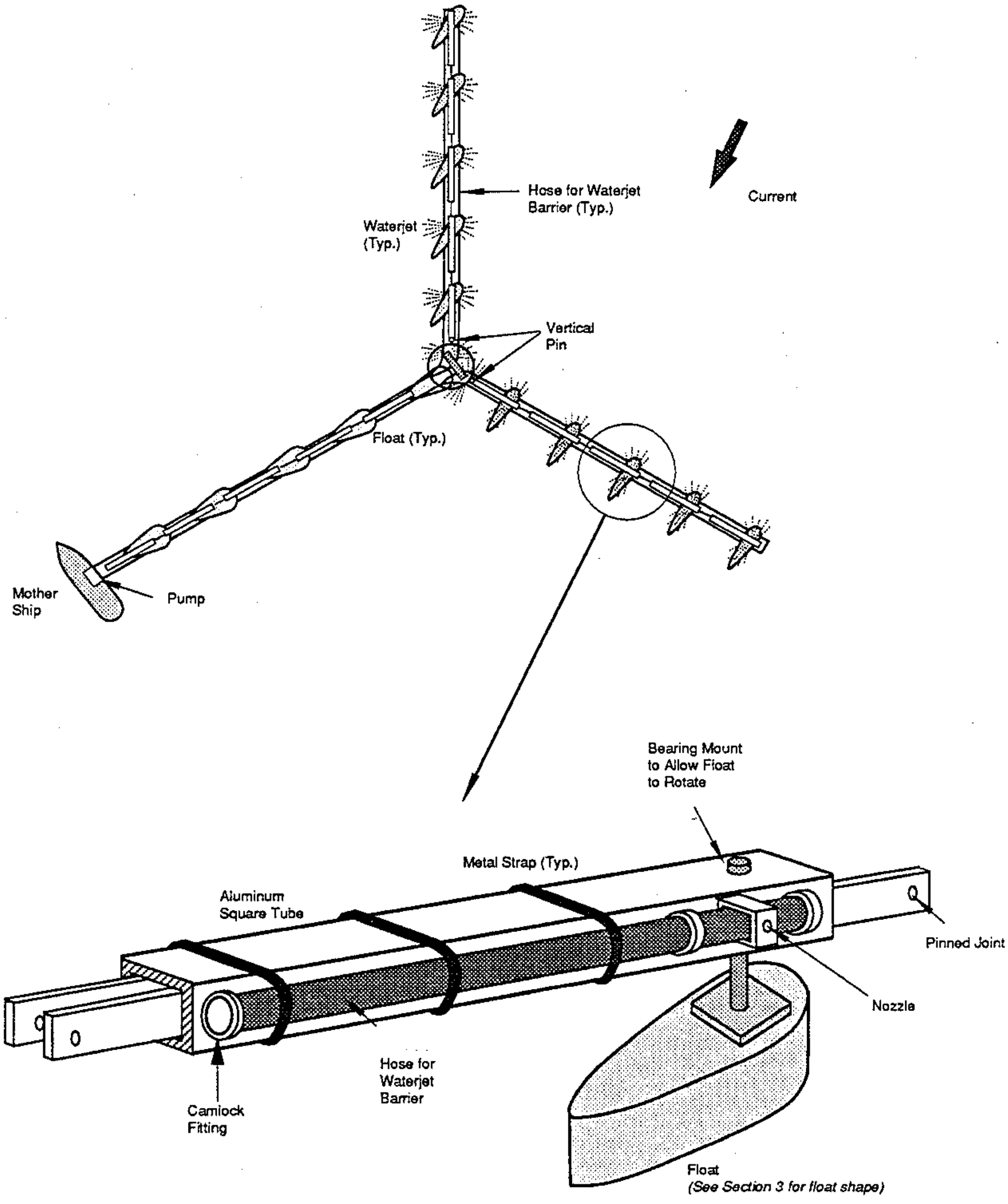


Figure 2.4: Waterjet Barrier General Arrangement

The two arms of the barrier will be joined using a vertical pin at the apex structure. This arrangement allows the operator to move each arm independently as a rigid unit in the horizontal plane to allow the apex angle to be opened or closed as desired while maintaining its stability. This arrangement also has the advantage (over a rigid joint at the apex structure) that it reduces the moments applied to the structural elements of the waterjet barrier, thereby reducing the required section and the weight of the barrier.

Nozzles will be added at the apex (see Figure 2.4) in an effort to reduce oil loss at the apex which has occurred during previous deployments.

For ease of assembly, demobilization, stowage, and replacement of parts, the barrier will consist of three main parts, as follows:

(a) Separate 2.4 m (8 ft) long sections with hoses attached to each side.

(b) Floats which attach to each section.

(c) The apex structure.

3.0 FLOAT DESIGN AND TANK TESTING

3.1 Objectives and Constraints in the Float Design

The new floats were designed to meet three main performance objectives:

(a) Support the weight of the barrier and maintain a nozzle elevation of approximately 20cm (8") above the waterline.

(b) Reduce the drag of the floats in currents up to about 2 knots (1 m/s).

(c) Improve the stability of the barrier under the action of the water jets.

The use of a rigid structure to support the barrier greatly improves its stability as the "Y" shaped configuration of the two barrier arms and the "umbilical" support is inherently stable. Thus the float design was focused on drag reduction. Stability remained a concern, nevertheless, as it is desirable that the arms have some tendency to float upright to facilitate joining the boom components during deployment.

Two measures were utilized to reduce float drag. The first was to halve the number of floats used to support the nozzles. This was largely made feasible by the adoption of a rigid structure. The individual floats required an increased displacement (size) to support the additional load, with correspondingly higher drag on that individual float. However it was felt that the drag penalty imposed by the increased float size would be small relative to the benefit gained by reducing flow interference between adjacent floats, and that this drag penalty would be offset by the use of a streamlined float form.

It was recognized that the drag of the existing disk-shaped float could be reduced significantly, and thus it was decided to abandon the disk configuration (which has an axisymmetric plan shape). As a result, two further design requirements were imposed in the development of a new float:

(a) the necessity for the float to "weather vane" in the current to maintain the most favourable orientation to minimize drag. This is achieved in an airfoil by locating the tow point ahead of the centre of drag when the float develops an "angle of attack" with the float; however the location of the tow point could not be arbitrarily placed ahead of the longitudinal centre of buoyancy (LCB) without creating a trim in the floats. Thus the distribution of volume along the length of the floats was critical to place the LCB ahead of the projected profile area (crudely approximating the centre of drag). In addition, the need for a skeg (fixed control surface) to be fitted aft was recognized.

(b) the requirement for the float to avoid excessive pitching motions in waves to maintain a flat waterjet spray. Previous tests have shown that the jets should be kept horizontal to work effectively. Thus the float form must be "fine" enough to "platform" (cut through the waves) rather than contour. However, the float form cannot be too fine to ensure that it has adequate stability, reserve buoyancy (to allow for weight growth), and strength.

The following practical design constraints were also identified.

(a) The deployment scenario and the storage requirements imposed size constraints. It was decided that a practical float length should not exceed two metres. This effectively constrained the size and geometry of the floats, in combination with dimensionless ratios (length/breadth, length/depth, location of maximum breath) typical of the streamlined concept. In addition, the length of the float aft of the pivot point could not be so great that two adjacent floats might interfere during "weathervaning". As the spacing of the nozzles on the boom is 2.4m (8′), an additional constraint on length was imposed.

(b) A second requirement was durability, again given the deployment scenario. Consequently, slender float designs and such features as fine trailing edges were considered to be inappropriate.

(c) Finally, it was recognized that the float configuration should be producible given the quantity of floats required. This eliminated more complex float geometries.

3.2 Design Concepts: Preliminary Analysis

According to classical theory (Hoerner, 1965), the float drag consists of two primary components: (a) "wave-making" drag at the free surface; and, (b) "skin-friction" drag, which is related to the wetted surface of the body. The wave drag component can be characterized by the Froude number, (i.e., the ratio of inertial to gravitational forces). For the design speed and expected length of 1-2 metres, the Froude number will range from 0.23 to 0.30. This range of Froude numbers falls in the medium to high speed range, where wave making resistance is significant.

The frictional drag component can be characterized by the Reynolds number, (i.e., the ratio of inertial to viscous forces). Based on the expected range of design speeds and float lengths, the Reynolds number was calculated to range from 9×10^5 to 2×10^6. As indicated by Figure 3.1, the flow conditions in this range are transitional between laminar and turbulent.

Thus, the dimensionless numbers indicated that both wave-making and skin friction drag need to be considered in developing concepts for the floats. Sketches of each concept considered are included as Figure 3.2. A brief description and preliminary evaluation of the various float configurations considered follows:

Concept 1: the original disk floats, now loaded to a deeper displacement.

The chief attribute of this concept (apart from the fact that it is axisymmetric) is that it minimizes wetted surface for the design displacement. However, the disk is a bluff form, with the least length, and therefore a high wave-making resistance. Vortex shedding can be expected over the design speed range. Nevertheless, this float was tested in the FTL model basin as the reference case.

Data on sectional drag (at ≈ zero lift) of streamline foil- and strut sections. Many of the experimental results are obtained by wake-survey technique; in others, drag of blunt wing tips has been subtracted from the original values. Drag coefficients at subcritical R'numbers are as indicated by equation 24 (using $C_f = 2.66\sqrt{R_c}$); at very high R'numbers as given by equation 28 (using C_f as indicated by the Schoenherr equation in Chapter II).

SYMBOL	SOURCE SHAPE	t/c%	r	REF
•	NACA - ELLIPTICAL	200	1	5.b
○	VARI'S CYLINDERS	100	1	III
◇	VARIOUS DITTO CL	100	1.5	III
•	AVA -- CYLINDERS	100	1	5.h
□	CYLINDER IN WIND	100	1	5.e
⊙	NACA WIND TUNNEL	100	1	5.b
■	DRYDEN - IN WIND	100	1	5.a
■	C O 7 O IN WATER	70	3	4.f
◇	A V A ---- STRUT	71	3	4.a
◇	A V A ---- STRUT	64	3	4.a
•	NACA - ELLIPTICL	50	1.5	5.d
G	ARC - ELLIPTICAL	50	1.5	4.e
□	NACA --- 3-THICK	50	2	4.d
◇	AVA -- S T R U T	49	3	4.a
■	DIN-L-92 STRUT	46	3	4.f
△	NACA - ELLIPTICAL	40	1	5.g
■	DIN-L-92 STRUT	37	3	4.f
▼	A V A JOUKOWSKY	36	1	3.b
△	NACA 0035 SECT'N	35	1	3.f
+	EIFFEL S T R U T	34	2	4.1
▽	ARC GLOSTER STRt	30	2.5	4.e
×	ARC 0030 SECTION	30	3	3.e
▼	A V A JOUKOWSKY	30	1	3.b
I	CAHI - S T R U T	28	3	3.e
>	NACA - ELLIPTICAL	27	1	5.g
X	ARC — S T R U T	25+	1	4.h
◇	A V A S T R U T	25	2	4.a
⊢	ARC, FLIGHT TEST	25	1	3.p
^	NACA S T R U TS	25	2	4.d
▽	A R C, 0025 FOIL	25	3	3.e
I	CAHI - S T R U T	25	3	4.c
•	NACA - ELLIPTICAL	25	1	5.d
⊢	ARC FOIL SECTION	24-	3	3.o
▲	NACA - 0025 FOIL	25	1	3.f
T	NACA - 0021 FOIL	21	1	3.l
◇	AVA, WIRE-STRUT	20	1	4.a
T	A R C JOUKOWSKY	13-	1	3.o
•	NACA - ELLIPTICAL	13-	1	5.d
⊢	A V A - 459 FOIL	12+	1	3.k
!	STEVENS 0 0 1 2	12	1	3.m
▼	ARC, GLOSTER STR	12+	2	4.e
+	NACA, FULL SCALE	12	3	3.f
×	ARC-CAT, 0 0 1 2	12	4	3.e
Y	NACA, LOW TURBUL	12	1	(7)
^	D V L, 0012 FOIL	12	3	3.i
▼	A V A JOUKOWSKY	11+	1	3.b
λ	NACA 0006 SECT'N	6	1	(7)
•	AVA, FOIL SECT'N	6	5	3.k
T	NACA 0006 SECT'N	6	1	3.l
—	NACA 0006 SECT'N	6	3	3.l
^	D V L, 0006 FOIL	6	3	3.l
/	A V A - CAMBERED	6	1	3.k
✱	RM 1117 CAMBERED	13	1	ARC

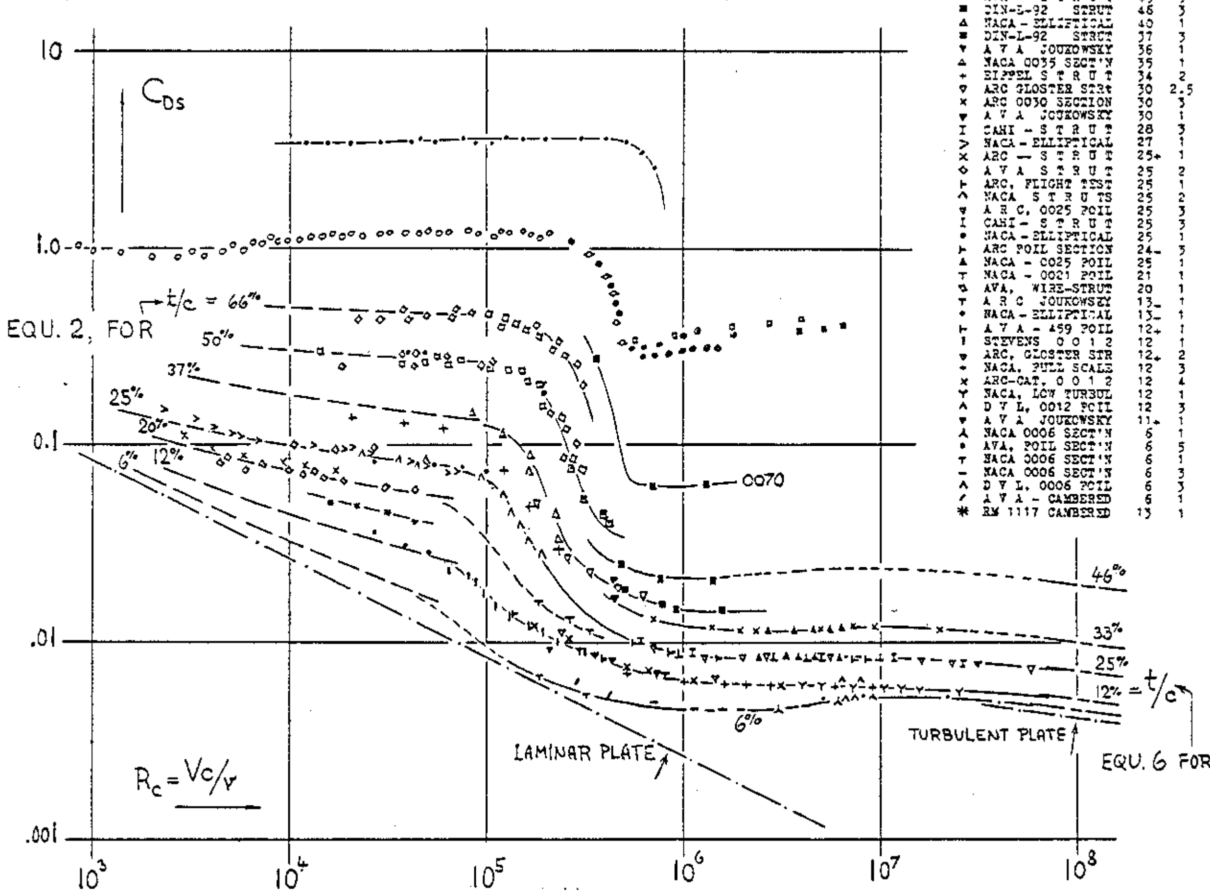
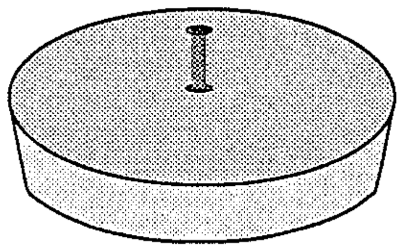
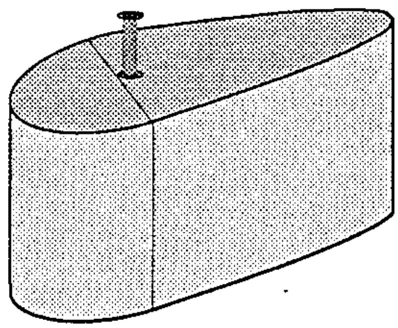


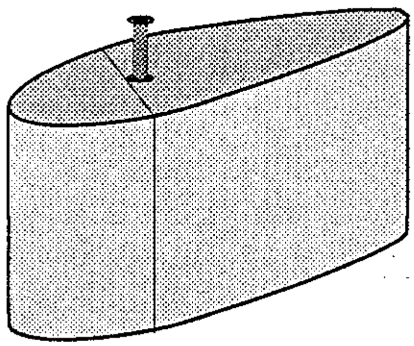
Figure 3.1: Section Drag Coefficients versus Reynolds Number



Disc Float
Diameter = 1 m
Depth = 0.15 m

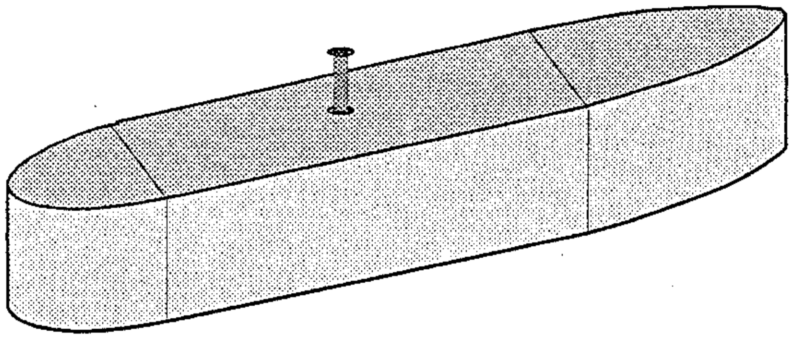


Float SF1
L = 1 m
B = 0.25 m
L/B = 4
Max. Chord = 0.3 from nose
Depth = 0.5 m

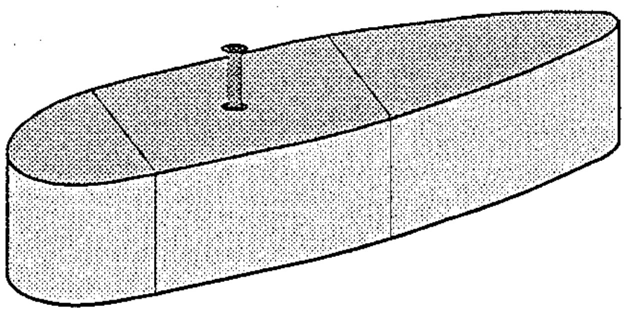


Float SF2
L = 1 m
B = 0.2 m
L/B = 5
Max. Chord at 0.4m from nose
Depth = 0.56 m

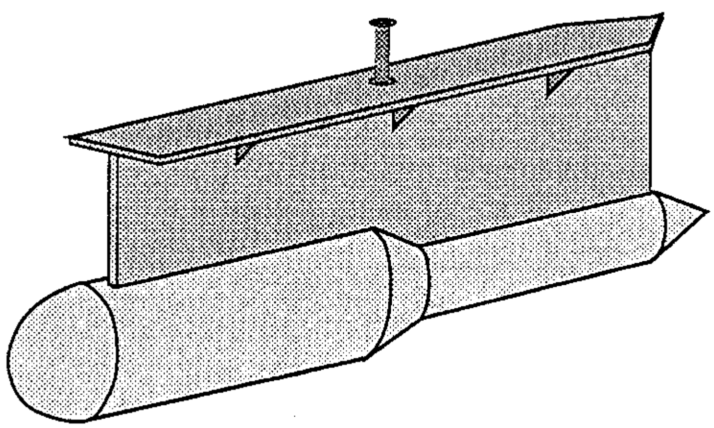
Figure 3.2a: Alternative Float Concepts



Float LF1
L = 2 m
B = 0.2 m
L/B = 10
Mid Body Length =0.1
@ 0.4 from nose
Depth = 0.30 m



Float LF2
L = 1.625 m
B = 0.25 m
L/B = 6.5
Mid Body Length =0.625
@ 0.3 from nose
Depth = 0.30 m



SWATH Float
Conceptual

Figure 3.2b: Alternative Float Concepts (cont.)

Concept 2: the "Airfoil Strut" float.

A basic airfoil shape offers good form drag characteristics and the best potential "weathervaning" response. Concept 2 was conceived as a section with an elliptical nose and parabolic tail; a fine trailing edge was considered too vulnerable. Design data obtained for the sectional drag characteristics of airfoils found in Hoerner (1965) suggested that an L/B ratio of 4 was appropriate. The concept was developed as a strut (i.e., greater depth to length), in order that heave (i.e., vertical translation) would be the dominant motion response in waves.

The major penalty associated with the "strut" concept is its length restriction, which results in high wave-making resistance at the upper speed range. It was unclear whether the superior form drag of the float would offset this resistance penalty. Another disadvantage of this concept is that it has low lateral stability when loaded due to its low centre of buoyancy. This is a concern for boom deployment and because of the potentially large moment that would be placed on the float pivot bearings.

Two designs were developed using Hoerner, 1965 for guidance, in which two critical parameters, (i.e., the L/B ratio and the position of maximum chord) were varied.

(a) **SF1:** the "standard" airfoil, with a length of 1m, an L/B ratio of 4, and the maximum breadth at 30% of the length from the nose.

(b) **SF2:** a "slender" airfoil, which is better suited to laminar flow with a 1m length, an L/B ratio of 5, and the maximum breadth at 40% of the length from the nose.

Concept 3: the "Boat Hull" float

The "boat hull" float was longer with a much shallower draft than the "airfoil" concept. Standard hull form ratios provided guidance with regard to an appropriate L/B ratio and the relative influence of other hull parameters. To obtain similar motion responses to the airfoil concept, the beam of the "boat hull" float was restricted to the same range (i.e., 0.2 -0.3m), as the "airfoil" concept's. Producibility and durability concerns precluded more complex hull shapes and finer hull sections. The design of this float was further constrained by limits on its length and LCB location.

In view of these constraints, the float was developed by inserting a parallel sided mid-section (i.e., parallel midbody) between the nose and tail segments designed for the airfoil floats. The elliptical nose section offers a good balance between the requirements for high displacement and low drag, while the long parabolic tail section ensures that the LCB is forward. Unlike the airfoil, a small bilge radius was introduced to reduce drag.

The major attribute of this concept is its increased length, which means it operates at lower Froude numbers and therefore has a lower wave making resistance, while still retaining good form drag characteristics. In addition, the concept features a large waterplane area, which allows for weight changes in the structure above, while still featuring a relatively slender hull form, which is necessary for "planing" (cutting) waves. The reduced draft of this concept places the vertical centre of buoyancy closer to the centre of gravity of the structure than the airfoil float.

The major concern with concept 3 was its ability to "weathervane" as its additional length placed the nose section well forward of the pivot while the parallel midbody resulted in a greater fore-aft symmetry. It was unclear that the drag pressures around the float would equalize without the addition of a skeg aft.

Two boat hull float designs were analyzed. However, the first design was intended as an extreme case, and was not really practical based on durability considerations.

(a) **LF1:** An extreme "slender" form based on an L/B ratio of 10, which is typical of fast liners and naval vessels. The length was taken as 2m, and the nose and tail were taken from airfoil SF2.

(b) **LF2:** A standard "slender" form based on an L/B ratio of 6.5, which is typical of cargo liners. With the nose and tail of airfoil SF1 and the pivot length constraint, its length was limited to 1.625m.

Concept 4: The "SWATH" float

The SWATH acronym refers to a class of vessel known as "Small Waterplane Area, Twin Hull"; where the structure is supported on narrow struts and submerged pontoons. The main attribute of this concept is that the narrow strut piercing the surface is insensitive to wave action. However this concept was discarded early in the evaluation for a number of reasons. The main buoyant hull is completely submerged and therefore the pontoon could be potentially be quite large to obtain the required displacement, with a correspondingly large frontal area. Stability is also dependent on weight distribution in the float (there being no effective waterplane) which would further increase the size of the float. If not adequately submerged the drag could be quite large, so that a deep strut was required. The narrow strut and fully submerged hull also meant that this float would have little reserve buoyancy and therefore would be very weight sensitive.

3.3 Preliminary Numerical Drag Estimates

The drag of each of the four candidate floats and the existing disk, was first estimated numerically based on empirical formulae in Hoerner (1965) and Comstock [PNA] (1967). Sectional drag estimates were prepared for each float oriented parallel to the flow. It should be noted that the numerical analysis did not contain an estimate for the wave-making drag component, as no simple formula was available for the shapes and flow conditions under consideration. Consequently the accuracy of the drag estimates was expected to change dramatically as speed increased and the wave-making component became more significant. Nevertheless the analysis was useful as it provided the following:

(a) An indication of the minimum drag forces likely to be encountered, with respect to design and calibration of the towing instrumentation used during full scale testing.

(b) A relative indication of the improvement in drag between the float types, and more importantly, an indication of the optimum values for design parameters and ratios (i.e., length, L/B, location of maximum beam) for each float type. In general it was concluded that the compromises imposed by practical considerations (size restrictions, durability, producibility) did not significantly impact drag reduction.

(c) A database for identifying the significance of the wave-making component from the total drag force measured in the model towing tests.

(d) An indication of which float designs had the least drag, and therefore, which float designs merited full scale testing. It was decided to conduct tests with floats SF1 and LF2.

The drag when the float was oriented perpendicular to the flow was also calculated to determine a "worst case" loading for designing the rigid structure. In this case the worst case drag estimate was predicted to be 1000 N. This number was subsequently used in estimating the moment that might act on the structure.

The numerical drag estimates are included in the tables and the plots accompanying the presentation of experimental results (Section 3.5) and in Appendix A.2.

3.4 Preparation for the Test Program

The final selection of the float configuration was based on the results of full scale prototype tests conducted in FTL's towing basin in Kanata. These trials had two objectives:

(a) Perform resistance trials to determine the total drag on each of the prototypes.

(b) Determine the weathervaning characteristics of the float with least resistance.

3.4.1 Lines Preparation

Preparation for the tests began with the generation of the dimensions of each of the prototypes. Each of the components of the existing waterjet barrier were carefully weighed, and the weight of the rigid structure in both fibreglass and aluminum was estimated. Waterplane sections were generated for each of the airfoil floats (SF1, SF2) and the boat hull floats (LF1, LF2) using the specified length and L/B, and closed form equations for the elliptical nose and parabolic tail sections. The waterplane area and waterplane offsets were calculated. The required depth for the float was determined using the weight estimates and the waterplane area, based on a freeboard of 7.6cm (3"). Float dimensions and their table of offsets are presented in Appendix A.1.

The table of offsets were plotted and faired using a standard drawing program. The sections were then plotted full-scale and used to prepare templates for fabrication of the models.

3.4.2 Model Fabrication

The models were fabricated by laminating layers of 5cm (2") blue styrofoam SM cut to the appropriate waterplane shape. The laminations were sanded and filled with a water-based putty, and then given a hard shell by applying two coats of epoxy resin. The final finish was obtained by sanding the rough spots on the shell; additional filling was not necessary.

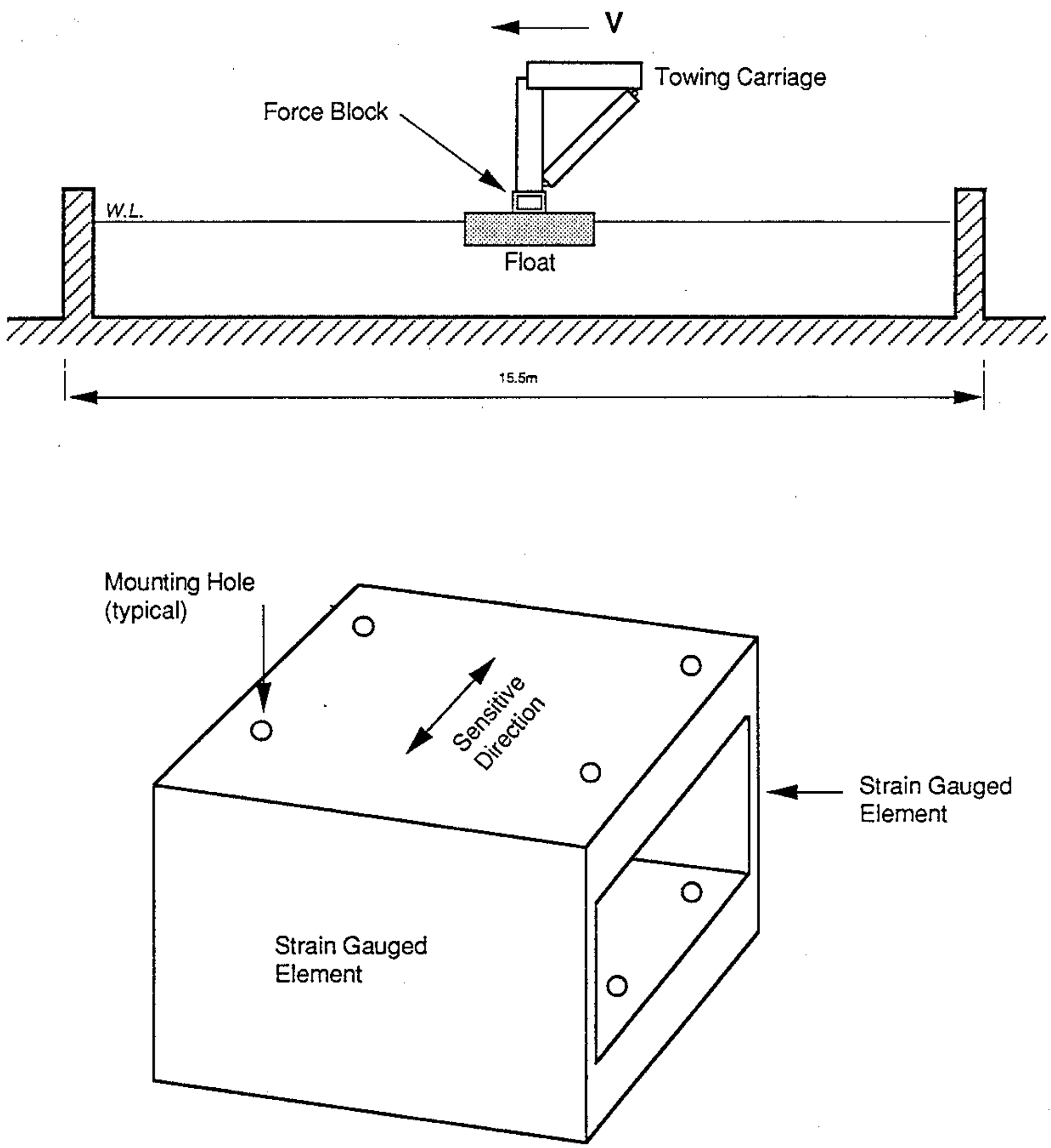
Each of the models was outfitted with an aluminum base plate with four exposed bolts used to fasten a cover plate for the towing post force block. The mounting bolts were located such that the force block would be centred over the LCB for towing.

3.4.3 Test Setup

The tests were conducted in FTL's towing basin in Kanata. A schematic of the towing arrangements is shown in Figure 3.3, along with the specifications for the force block used in the tests.

The time history of the drag force (i.e., resistance) and the carriage position were measured during each test. The signals were sampled at 50 Hz and filtered at 5 Hz before storage and processing using a Hewlett Packard 9816 computer.

The second part of the program involved testing the weathervaning capability of the float selected from the resistance trials. In these trials the float was fastened to the existing FTL heave staff, which has a roller bearing that allows the model to freely rotate in yaw (ie., in the plane of the waterplane). The model was towed from an initial position set at an angle to the direction of towing. The turning response of the model was recorded on videotape as it was being towed. The float was judged on whether it aligned itself fully with the towing direction over the length of the trial.



Force Block Data

Force Block No:	9
Outside Dimensions:	10cm x 10cm x 10cm (4in x 4in x 4in)
Wall Thickness:	1.6mm (.0625in)
Capacity:	250 N (50 lbs)
Sensitivity:	7.0097×10^{-4} mv/V/N

Figure 3.3: Experimental Apparatus

3.5 Results of Resistance Trials

Resistance tests were performed with full scale prototypes of:

(a) the disk float,

(b) the airfoil float, SF1,

(c) the boat hull float, LF2.

The trials were performed over a speed range of 0.3 - 1.0 m/s (0.6 - 2 knots). A total of 31 tests were carried out. At least two tests were performed at each speed. Several tests were performed at the top end of the speed range, where the resistance increased dramatically.

The mean measured resistances for each model are given in Table 3.1 and plotted in Figure 3.4. Sample raw data are presented in Appendix A.3. The data for each test were analyzed statistically and these results also can be found in Appendix A.4. Figure 3.5 compares the test results with numerical estimates of the drag of each float. The predicted values are less than the measured results, particularly at high speed, which is to be expected as wave-making drag was not included in the numerical drag calculation.

The test data clearly show that float LF2 had the lowest drag. This conclusion was supported by observations of the wave pattern associated with each float. Strong vortices were seen when the disk was towed at speed, while a conventional but quite severe wave system was observed with the airfoil float. The rapid rise in resistance of the airfoil float at the upper speed range suggests that the float may have exceeded "hump speed" at the highest speed increments (i.e., the float may have been outrunning the wave system). In comparison, wave-making was significantly redued at high speed for the LF2 "boat hull" flot. See Figure 3.6. This improvement resulted from the additional length of float LF2, which reduced the Froude number at which this float operated.

TABLE 3.1

TEST RESULTS SUMMARY

A. Summary of Experimental Resistance Results for Waterjet Floats

	Model:	*Disk*		*SF1*		*LF2*	
		Mean	Std.	Mean	Std.	Mean	Std.
V(knots)	V (m/s)	Rm(N)	Deviation	Rm(N)	Deviation	Rm(N)	Deviation
0.58	0.3	2.2391	1.463	0.689	0.7471	0.6506	0.4402
0.58	0.3	2.3418	1.4041	-	-	0.5265	0.4837
0.97	0.5	6.375	2.567	2.0869	1.0285	1.0785	0.7821
0.97	0.5	6.382	2.508	1.9151	1.0052	1.0392	0.8287
1.36	0.7	12.246	3.42	4.5498	1.6209	1.9985	1.1893
1.36	0.7	12.35	3.637	4.6376	1.6213	2.3818	1.2172
1.55	0.8	-	-	6.803	1.545	3.7254	1.3167
1.55	0.8	-	-	7.142	1.576	3.3456	1.2321
1.75	0.9	-	-	11.407	2.39	5.844	1.624
1.75	0.9	-	-	11.313	2.357	7.579	2.503
1.94	1	25.253	7.007	15.117	2.906	9.16	2.246
1.94	1	25.453	6.9	15.141	2.973	8.162	2..427

B. Measured Thrust Developed By Waterjet:

1) At 500 psi: Thrust = 62.4 N

2) At 1000 psi: Thrust = 106.4 N

NUMERICAL DRAG ESTIMATE SUMMARY

Velocity (m/s)	Predicted Resistance (N) of:	
	SF1 Float	LF2 Float
0.3	0.86	0.67
0.5	2.11	1.66
0.75	4.32	3.40
1	7.20	5.70

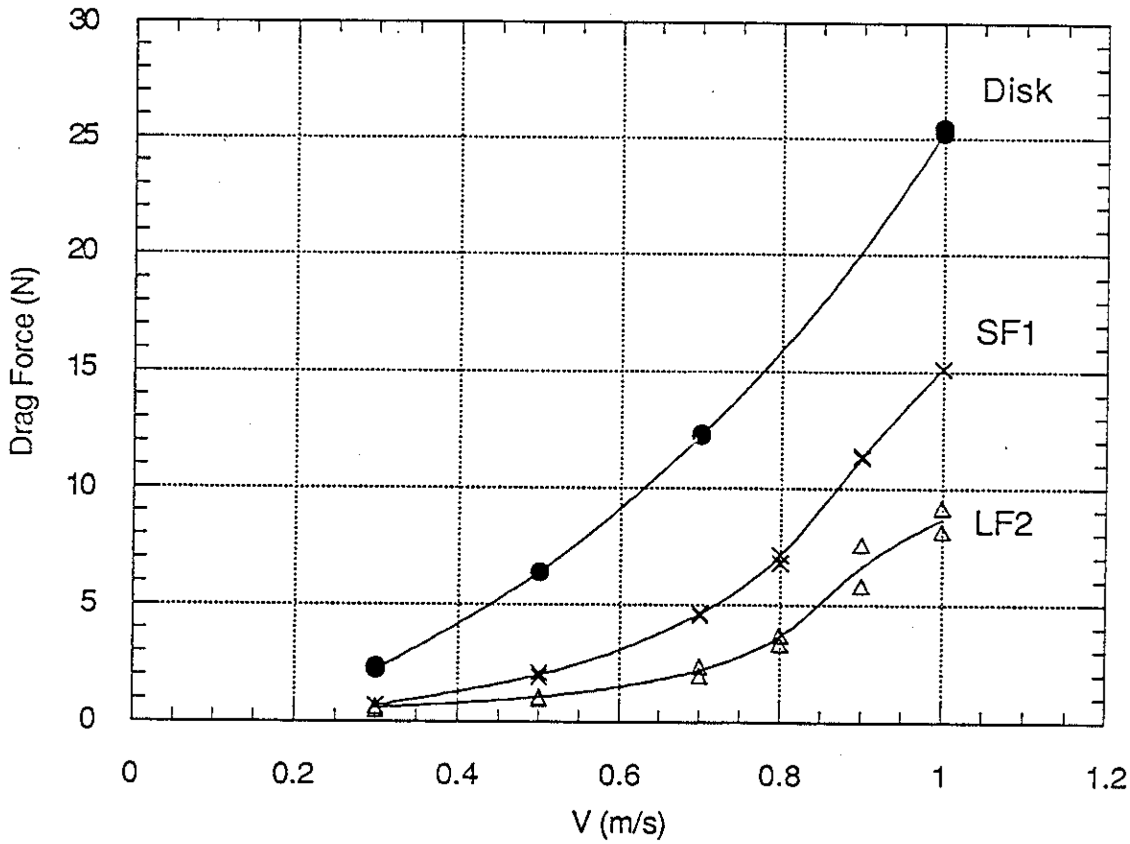


Figure 3.4: Measured Drag Force for Each Float

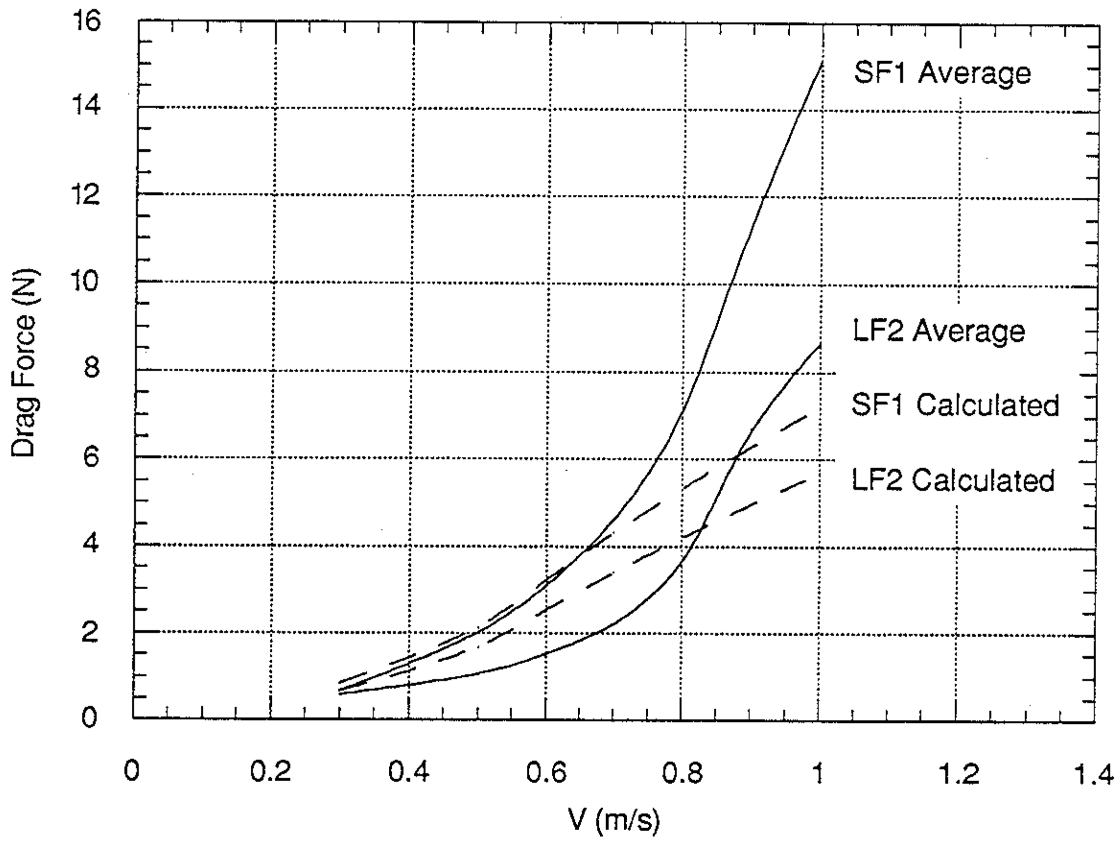
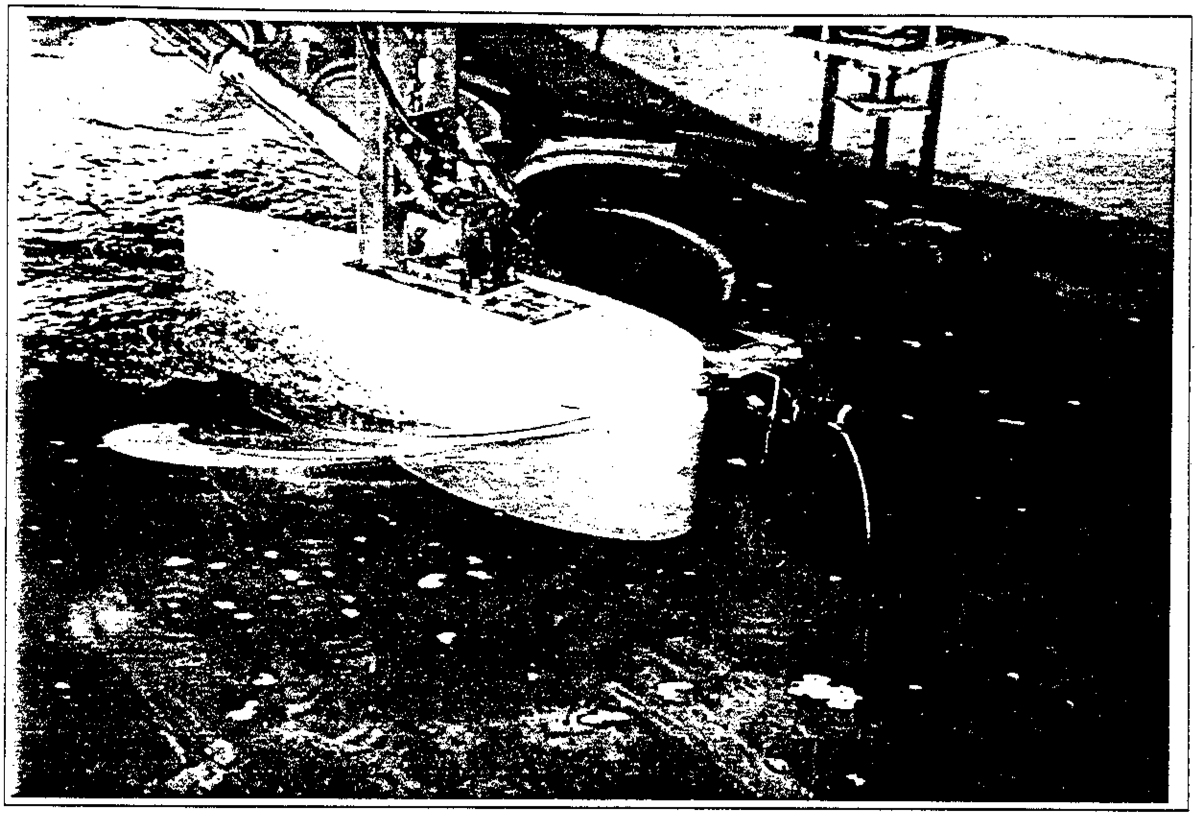
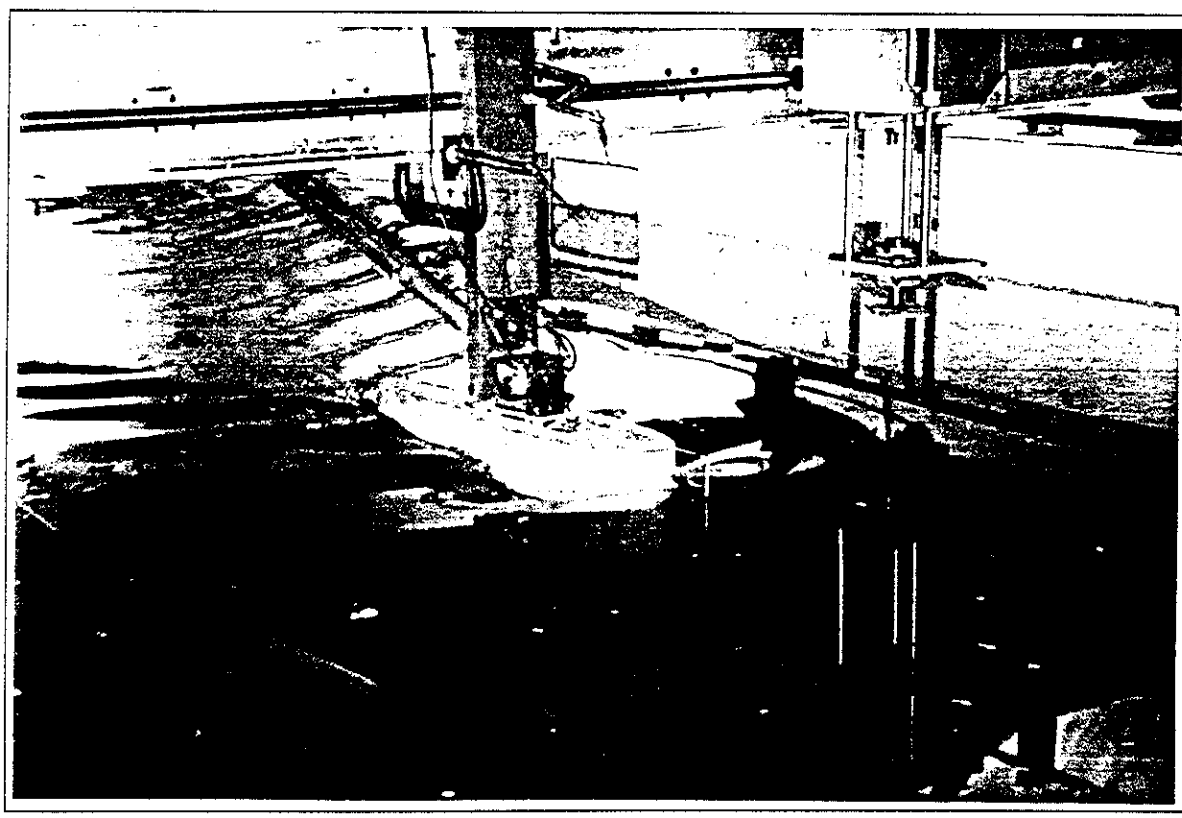


Figure 3.5: Measured Vs. Numerical Drag Estimates



SF1



LF2

Figure 3.6: Comparison of Wave Systems at High Speed; SF1 and LF2

3.6 Weathervaning Trials

Weathervaning trials were performed systematically using float LF2, as this float had the least resistance. The model was towed at initial orientations of 0, 45, 135, and 90 degrees to the towing direction. It was towed at 0.5 m/s for most runs, followed by low speed tests at 0.3 m/s and a high speed test at 0.7 m/s. The existing FTL heave staff was found to have some pivot bearing misalignment which acted to pull the model off centre. This bearing misalignment was not corrected because it was recognised that a similar problem might occur in the field. Thus, the tests are believed to represent relatively severe conditions.

The initial trial was performed without any skeg fitted to the float. It was quickly apparent that a pivot axis location at the LCB of the float was not far enough forward as the model did not align itself with the towing direction. This problem resulted from the pressure distribution around the nose which acted to pull the model off-centre.

Two options were available to obtain the required weathervaning performance using float LF2. The first option was to move the pivot point sufficiently forward to cause weathervaning. However, moving the pivot point forward of the LCB would cause the float to trim by the bow, which would result in difficulties in assembling the boom. Furthermore, this would introduce a twisting moment in the rigid structure once the boom was assembled.

The second option was to fit a skeg, (i.e., a flat vertical plate) to the stern of the float which would alter the pressure distribution along the float length without adding displacement. Test skegs were fabricated simply by cutting plywood to the appropriate dimensions and were fixed by a brace on the float deck.

The first skeg configuration extended along the depth of the float (approx. 30cm (12")) and had a length (chord) of 15cm (6"). This length took the overall length of the float to the maximum aft body length allowed before the float might interfere with an adjacent one. This skeg failed to adequately weathervane the float as the float would point up to about 45° and stall.

The next skeg configuration tested was an "L" profile, with the foot of the "L", or keel, running forward under the float to the parallel midbody. This configuration was selected because it offered the best increase in skeg area for the minimum increase in depth of the float and no increase in length. Restricting the depth of the float was desirable for deployment in shallow water, and for durability. The "L" skeg was tested systematically by varying the depth of the keel from a maximum of 30cm (12") to a minimum of 10cm (4"). A "tee" cross-section was also tested. The minimum effective keel depth was found to be 15cm (6"); this version was selected for the production version of the floats.

3.7 Waterjet Force Measurements

Tests were conducted to measure the reaction force exerted from a single waterjet nozzle. The object was to compare the force created by the nozzle with the hydrodynamic drag forces on the float.

A single nozzle was mounted on the towing post on the model towing carriage, and connected to the pump through the manifold. Force data was recorded for several minutes at the test pressure to allow the system to stabilize. Tests were conducted at operating pressures of 3.4 mPa (500 psi) and 6.9 mPa (1000 psi). Higher operating pressures could not be reached as the diesel stalled under these conditions.

The results of these tests are included in Table 3.1. The mean nozzle reaction force of about 100 N at 1000 psi was well below the maximum drag estimated for a perpendicular float (i.e., about 1000N) which is the case used in the design of the rigid structure. The results also suggest that there will be adequate nozzle thrust available to manoeuvre the barrier on correctly weathervaning floats.

3.8 Selected Float Concept

The LF2 form was selected as the conept for the floats as it has significantly less drag and it has acceptable "weathervaning" capability, after a skeg has been fitted to it. Section 4.1 presents design details for this float.

An added advantage of the LF2 form is that it can easily meet the requirement for larger floats to support the umbilical structure of the barrier. Along the umbilical there will be four hoses (instead of two) and hence, the supporting floats need to be correspondingly larger. Additional displacement is also required for the float at the junction of the "Y", because of the weight at the apex of structure. With the boat hull float, the added displacement is easily obtained with additional depth and the same waterplane size, rather than an overall increase in dimensions. This facilitates the production of the floats.

4.0 DETAILED DESIGN

4.1 Detail Design of the Waterjet Barrier Floats

4.1.1 Fabrication of the Float Hull

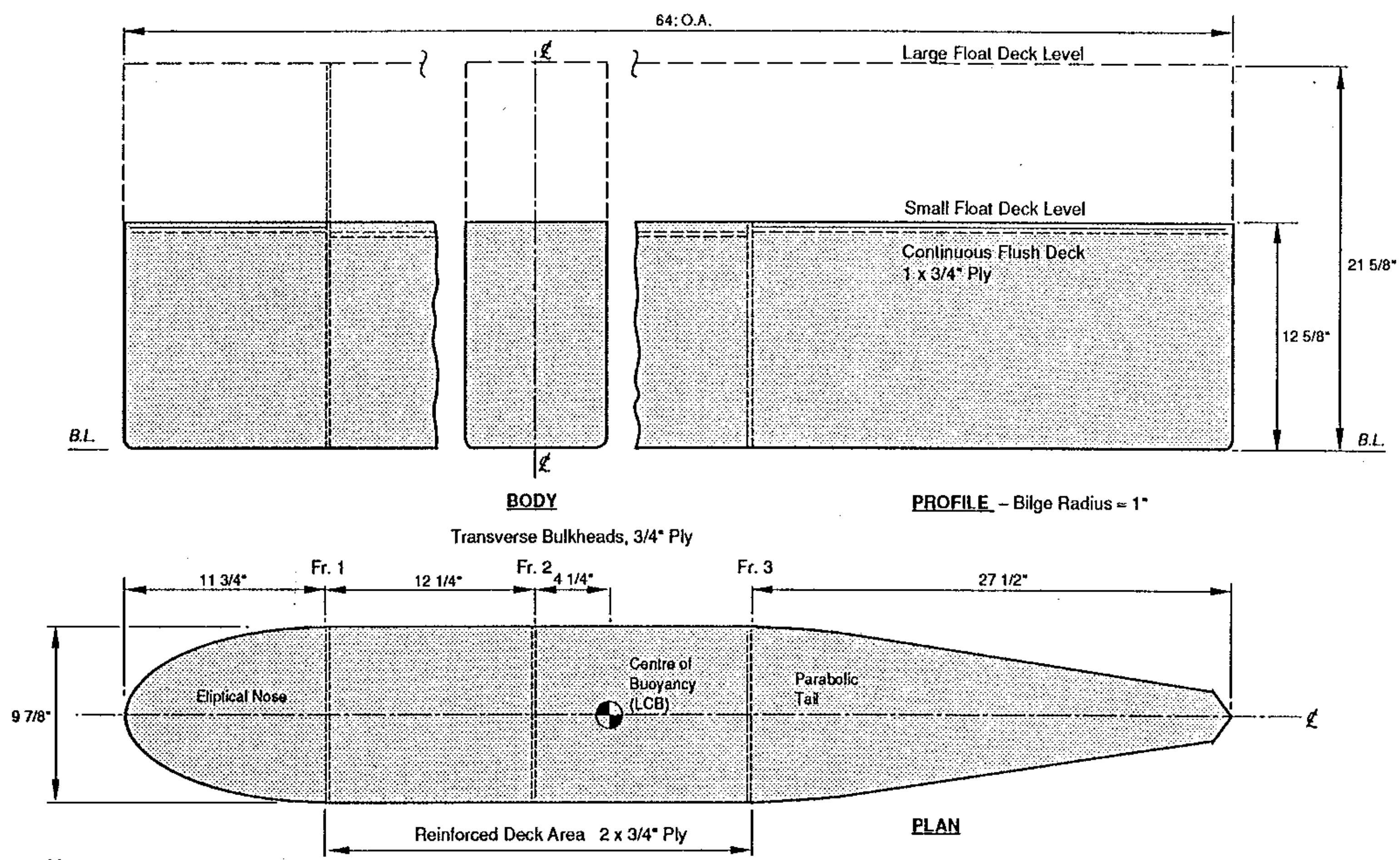
A general arrangement of the float excluding the skeg is shown in **Figure 4.1.** The quantity of floats required for the complete waterjet barrier can be efficiently produced using conventional fibreglass boat building methods. These techniques are much better suited to quantity production because a re-useable mold is used to produce the hull shell.

The hull shell is made of fibreglass formed in the mold, with a hard smooth, Gelcoat exterior. Pigment is added to the Gelcoat to give the float a specified colour; orange was specified. This shell is reinforced with 3/4" (1.9cm) plywood transverse frames and a full-length 3/4" plywood deck. The frames are concentrated in the mid-body to support the load exerted by the pivot mounted at the LCB. A double thickness of plywood decking is also fitted in the midbody to provide a solid foundation for the pivot. Two plywood blocks (not shown in Figure 4.1) are installed in the aft body to provide foundations for attachment of the skeg. All the internal spaces are filled with flotation foam, which provides additional stiffness for the shell, and seals the hull against flooding.

As noted in Section 3.8, larger floats are required to support the weight of the umbilical sections and at the apex than along the barrier boom. It was possible to limit the float depth to two sizes by designing the large float to the weight requirement of the apex structure, and then designing the rigid structure to be supported at a higher freeboard (lower displacement) along the umbilical arm. Refer to Section 4.2. for more detail. It was desirable to limit the number of float sizes to simplify assembly.

Each float at the ends of the barrier arms will only carry the weight of half the barrier structure. Again to standardize the float sizes, it was decided that it was preferable to ballast the end floats. It was preferable to outfit two floats to take removable weights, as the total ballast of 30kg (60 lbs) would lead to an unacceptably heavy float if the ballast permanently fixed. These two floats are fitted with bolting points on the upper deck, and will be identified by their yellow colour.

Detailed tables of the weight estimates used to size the final dimensions of the floats are provided in Appendix B.



Notes:

1. Two float sizes required. Same plan, varying depth.
2. Dimensions converted from metric to nearest 1/8".
3. Floats fabricated as fibreglass shell with 3/4" plywood frames and deck.
4. Internal compartments filled with flotation foam.
5. Plate skeg to be fitted aft (Ref. xx)
6. Mounting plate for rigid boom to be screwed over LCB into reinforced deck, centred. (Ref. yy, zz)
7. Misc. Floats to be fitted with cleat on deck fwd.

References:
xx: Skeg Details
yy: Float Attachment Detail
zz: Apex Structure

FLEET TECHNOLOGY LIMITED

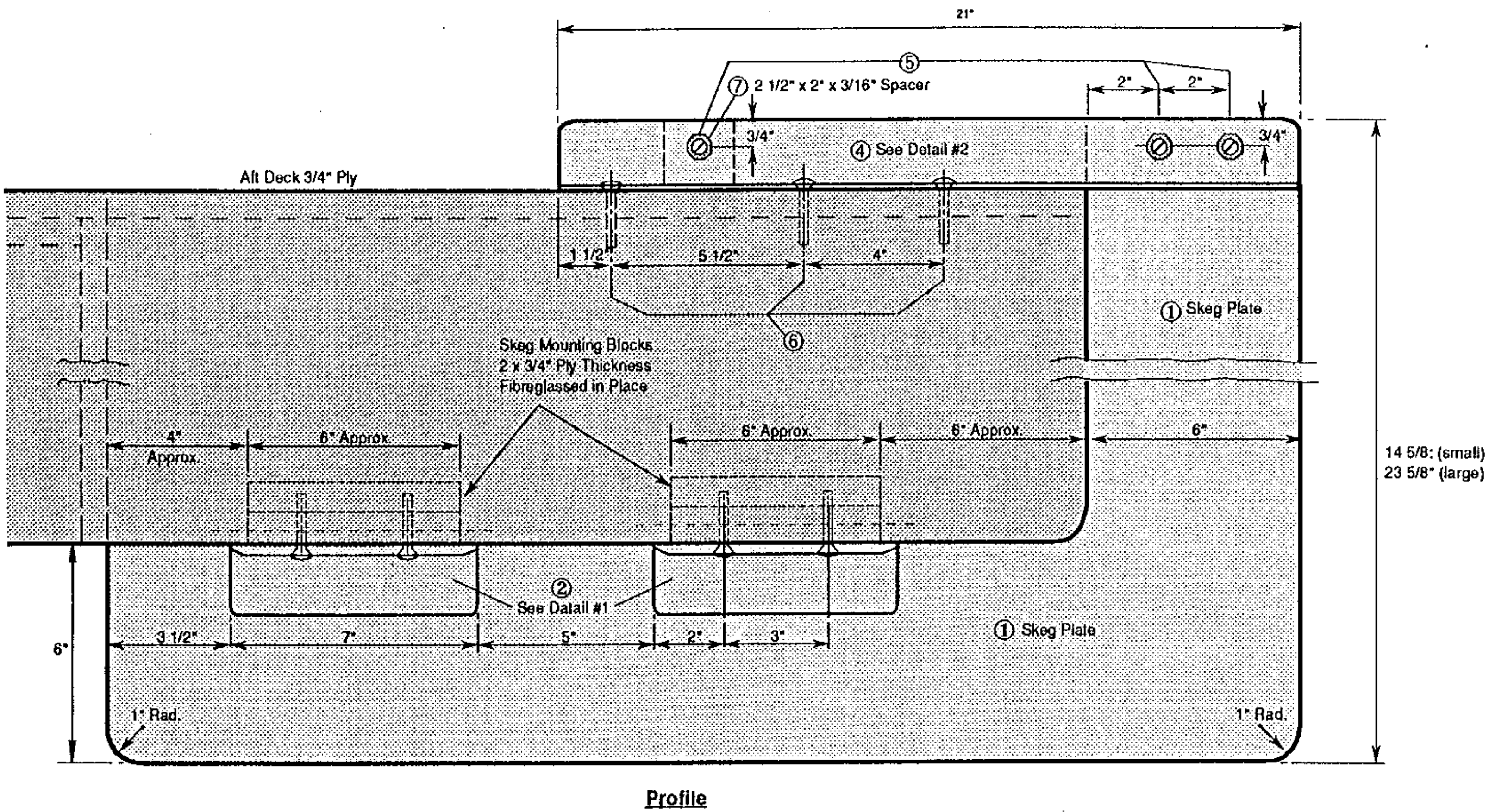
Title:	Barrier Float General Arrangement	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922-6	Scale:
Date:	28/2/91	

Figure 4.1: General Arrangement of Float

4.1.2 Fabrication of the Float Skeg

Details of the float skeg are shown in Figure 4.2. The basic dimensions of the skeg were determined in the weathervaning trials described in Section 3.6. It was decided to fabricate the skeg in aluminum as it is light, strong, and durable. A plate thickness of 3/16" (0.5cm) was selected because it was the minimum thickness that was considered to provide adequate lateral strength and that could be welded without distortion.

The skeg plate is attached to the float hull through 2"x 2"x 1/4" (5cm x 5cm x 0.635cm) aluminum angle brackets. The edges of the keel plate angle were extensively rounded (faired) to minimize parasitic drag. The keel plate angle is welded directly to the keel plate, and the entire assembly is fastened to the float hull using screws. The screws penetrate the shell into foundation blocks, and are sealed with silicone. The upper angle brackets bolt to the skeg plate and are fastened to the float deck using screws. The entire skeg assembly is designed to be removable in the event of damage to the skeg plate.



Parts List

No.	Item	Qty
①	Skeg Plate, 3/16" Aluminum Plate, Cutting Dimensions shown. See Note 1.	1
②	Keel Skeg Brackets, 2" X 2" X 1/4" Aluminum Angle, 7" Length. See Note 2.	4
③	1/4" Dia. Wood Screws, approx. 1 1/2" lengtth, Auminum. See Note 3.	8
④	Upper Skeg Brackets, 2" X 2" X 1/4" Aluminum Angle Cut To 21" Length. See Note 1.	2
⑤	1/4" Dia. Stainless Steel Bolts; Washers and Nut Not Shown.	3
⑥	1/4 " Dia. Wood Screws, Approx 3/4" Length, Aluminum. See Note 3	6
⑦	3/16" Aluminum Spacer Plate; Dimensions Shown.	1

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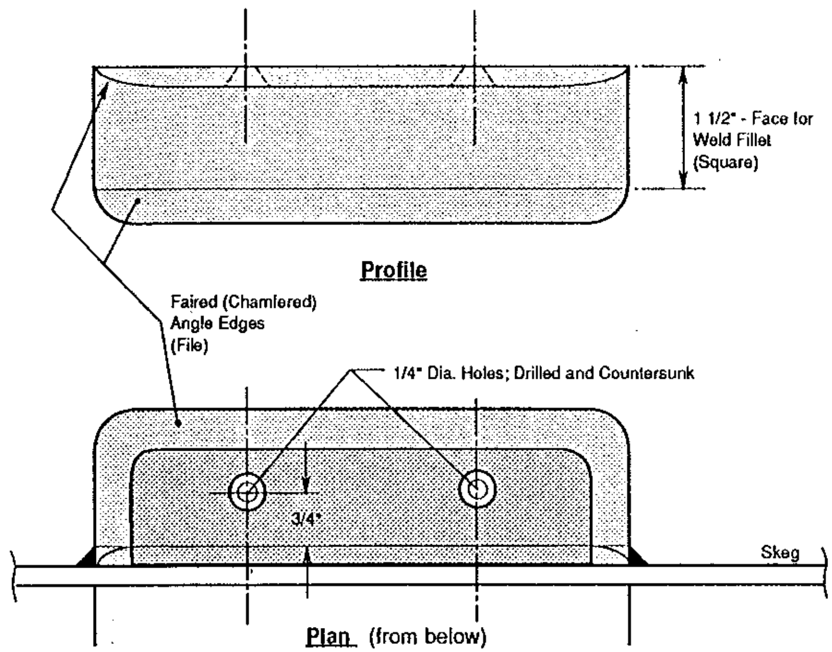
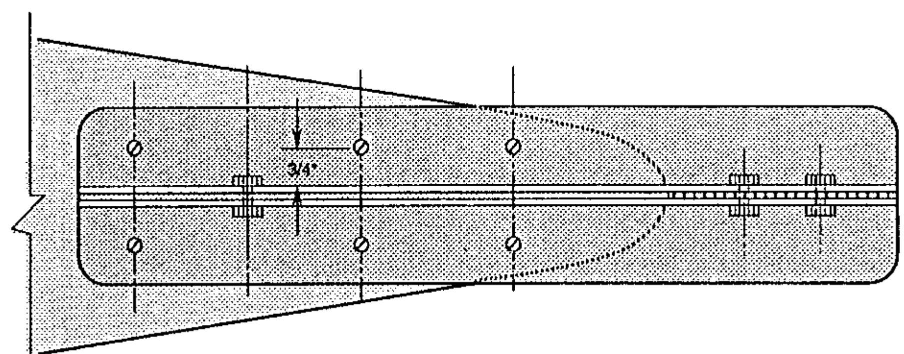
Title:	Float Skeg Details	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922-7	Scale:
Date:	28/2/91	

Figure 4.2a: Float Skeg Details



Detail #1: Keel Skeg Bracket



Detail #2: Plan View of Upper Skeg Bracket

Notes:

1. All corners on plate angles to be rounded even where radius not shown.
2. Keel skeg brackets (item ②) to have all edges faired (chamfered) as shown; screw heads to be countersunk.
3. All screws to be drilled and sealed with silicone.

FLEET TECHNOLOGY LIMITED		
Title:	Skeg Details for Barrier Floats	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922-7 cont.	Scale:
Date:	28/2/91	

Figure 4.2b: Float Skeg Details *(cont.)*

4.2 Waterjet Barrier Structure

4.2.1 Hose Support

Several criteria were used to select and design the hose support system, including:

(a) ability to support the design loading;
(b) ease of fabrication and simplicity;
(c) durability;
(d) weight minimization;
(e) cost.

Several scenarios were considered in order to establish the design loading. The greatest loads are predicted to occur during deployment or retrieval of the barrier. The following loading cases were selected for design:

(a) Case #1: One 2.44m (8 ft.) long section of the boom is cantilevered off the aft end of the ship. This is most likely to occur during deployment of the first float or retrieval of the last float. In this case, the beam would be required to support the in-air weight of the float (200N) and the weight of the water-filled discharge hoses in addition to its self-weight (i.e. a total of 200 N/m).

(b) Case #2: Two 2.44m (8 ft.) long sections become locked together and are pulled as a unit onto the aft end of the ship. The following was assumed:

- the float at the beam's mid-point is lifted completely out of the water.
- the float in the water at the end of the beam becomes oriented at 90° to the current. The current and the centre of drag were assumed to be 1 m/s and 0.5m below the beam, respectively.
- the beam has pinned ends.

In this case, the beam would be required to support the in-air weight of the float (i.e. 200 N), its self-weight, the uniformly-distributed weight of the water-filled discharge hoses (i.e. 200 N/m), and the moment produced by the current drag acting on the end float in the water (i.e. 500 N•m).

The maximum bending moments and shears resulting from these loading cases are summarized below:

Case #	Maximum Bending Moment (N•m)	Maximum Shear Force (N)
1	1083	688
2	1089	690

The design bending moment and shear force were taken as 1100 N•m and 700 N, respectively.

Sections in aluminum and fibreglass composite were evaluated for this design loading. Hollow Structural Sections (HSS) were selected for each material as this beam geometry simplifies the fabrication and assembly of the waterjet barrier. Furthermore, this section has good torsional resistance in comparison to other available sections. The minimum size of the HSS section was set at 7.62 cm (3 in.) to facilitate strapping the discharge hoses (which have an outside diameter of about 5 cm (2 in.) to the beam.

An aluminum HSS was chosen using working stress design principles. The selected aluminum HSS section provides a factor of safety of 2.9 against yield in bending and a factor of safety of about 150 against yield in shear. Design in composite materials is usually deflection-based (G. Murphy, General Composite Technology Ltd., personal communication), and a fibreglass composite section was recommended by General Composite Technology Ltd. based on these principles (Morrison Molded Fibreglass Company).

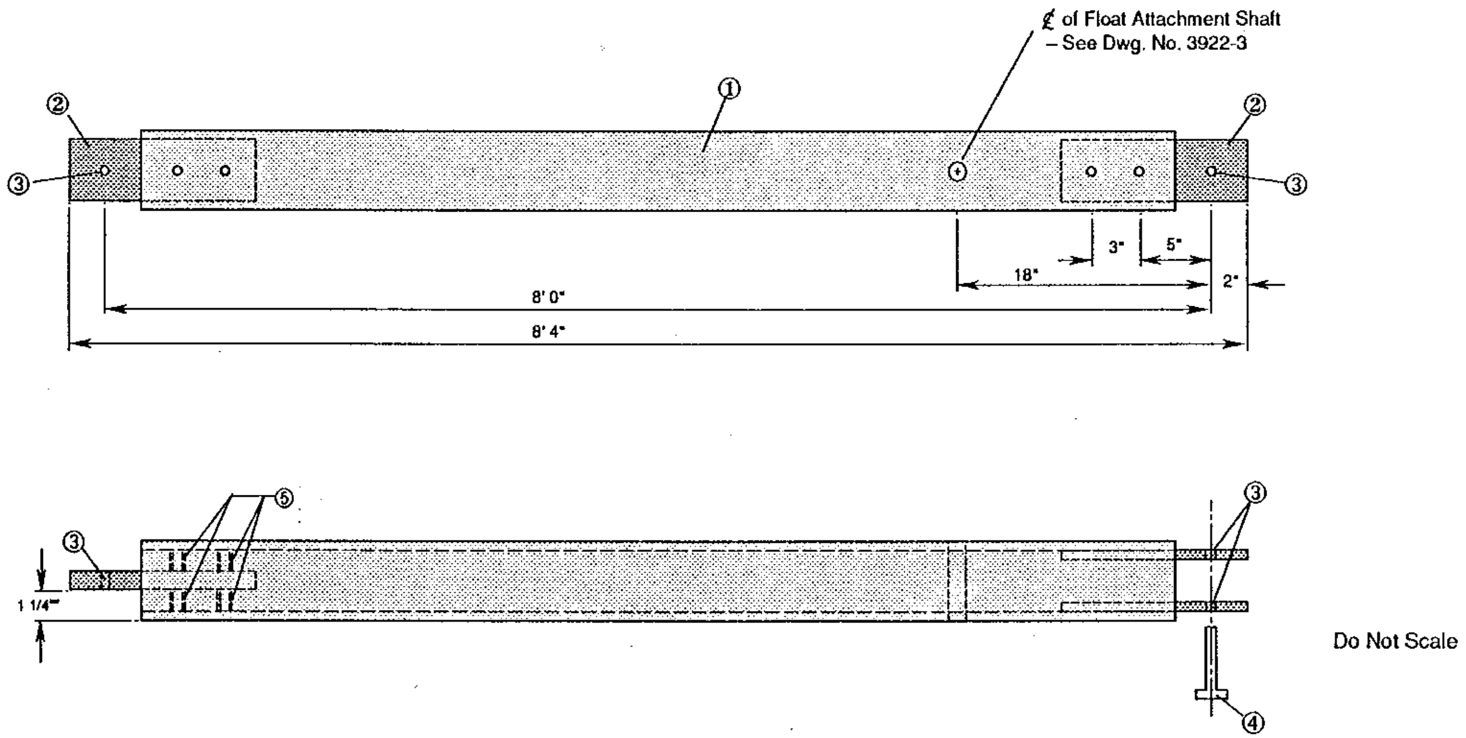
The selected sections in aluminum and fibreglass composite are compared below:

Material	Section Dimensions	Weight
Aluminum	7.62cm X 7.62cm X .64cm (3" X 3" X .25")	47 N/m (3.22 lb/ft)
Fibreglass Composite	10.2cm X 10.2cm X .64cm (4" X 4" X .25")	42 N/m (3.08 lb/ft)

There is a small weight advantage to a fibreglass composite section. However, the advantage is slight and the fibreglass composite section is more costly than the aluminum one (by a factor of more than 2), and had a significantly longer delivery period. In view of these disadvantages, it was decided to use an aluminum 3" X 1/4" HSS section for the prototype waterjet barrier.

4.2.2 Float Attachment and Apex Structure

Figures 4.3 to 4.7 provide a detailed description and parts list for the float attachment arrangement and the apex structure.



Parts List

No.	Item	Qty
①	3" x 3" x 0.25" 6061–T6 Aluminum HSS	1
②	2 1/2" x 15" x 0.5" Aluminum Plate	3
③	0.567" x 0.5" Teflon Cylindrical Bearing	3
④	0.567" Dia. Stainless Steel Bolt c/w Locking Pin	1
⑤	0.625" Dia. x .035" Wall x 1" Long Aluminum Tube	4

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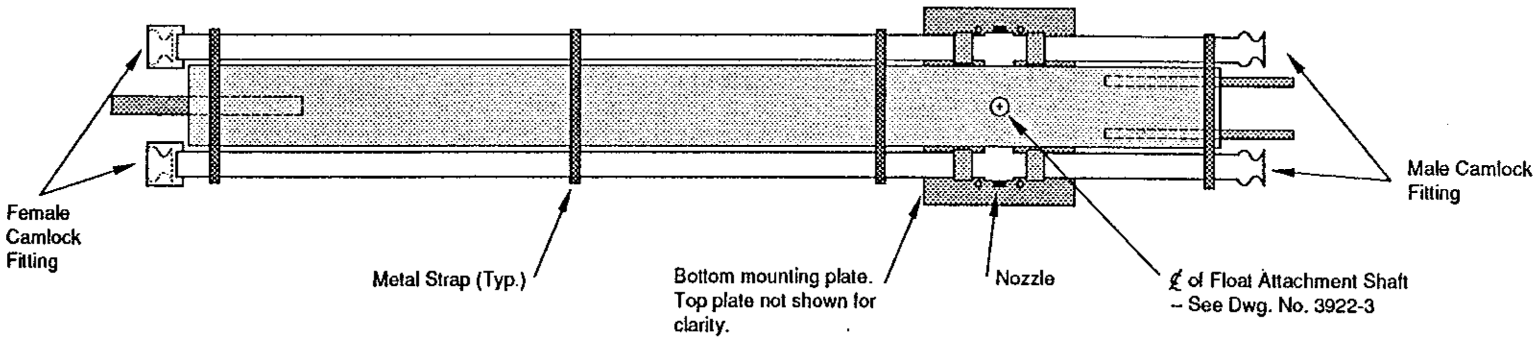
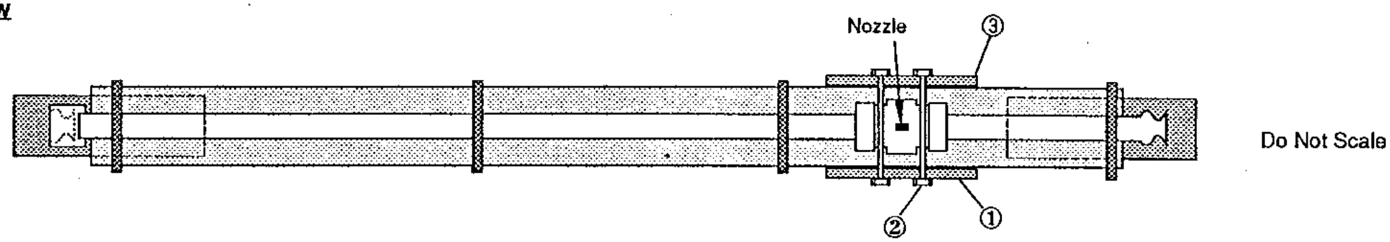
Title:	Barrier Arm Support	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922-1	Scale:
Date:		

Figure 4.3

Top View



Side View



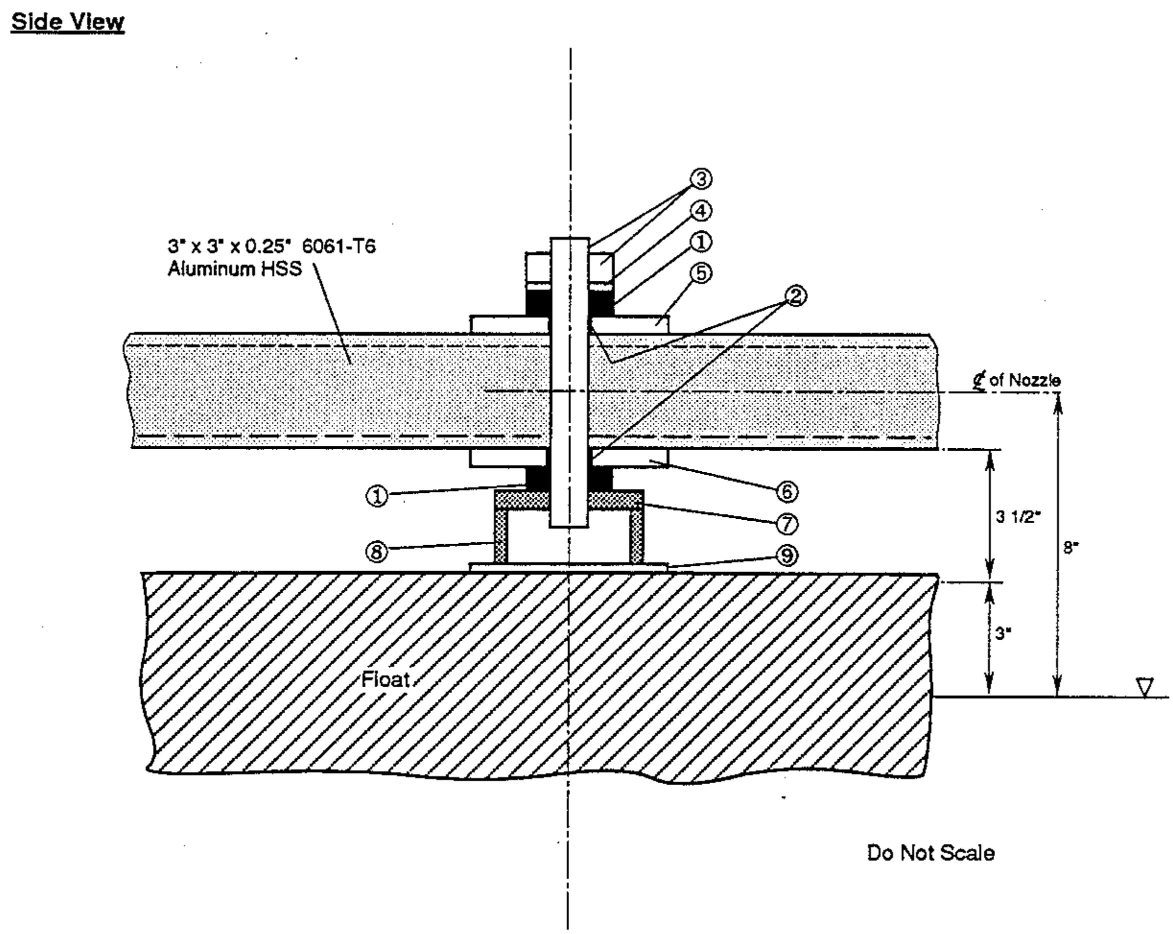
Parts List

No.	Item	Qty
①	5" x 5" x 0.5" Aluminum Plate	1
②	0.375" Dia. x 5" Long Stainless Steel Bolts	4
③	5" x 5" x 0.5" Aluminum Plate	1

FTL FLEET TECHNOLOGY LIMITED

Title:	Attachment of Discharge Hose & Nozzle to Barrier Arm Support	
Project:	Waterjet Barrier	
Project No.	3922C	
Dwg No.:	3922-2	
Approved:		Scale:
Date:		

Figure 4.4



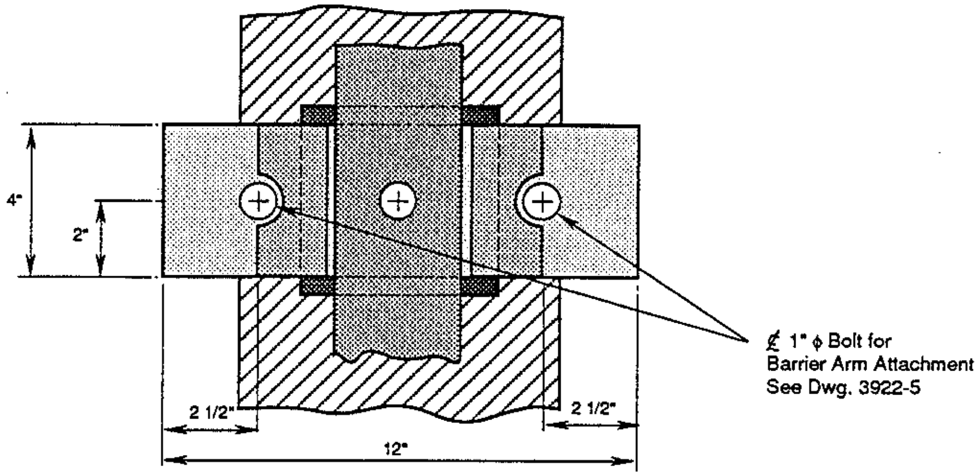
Parts List

No.	Item	Qty
①	2" OD x 1" ID x 0.5" Teflon Thrust Bearing	2
②	1" ID x 0.75" Long Teflon Cylindrical Bearing	2
③	1" ID x 7" Long Stainless Steel Shaft	1
④	2" OD x 1" ID x 0.125" Stainless Steel Washer	1
⑤	5" x 5" x 0.5" Aluminum Plate	1
⑥	5" x 5" x 0.5" Aluminum Plate	1
⑦	3.5" OD x 1" ID x 0.5" Stainless Steel Plate	1
⑧	3" Nom. x 1.75" Long Sched. 40 Stainless Steel Pipe	1
⑨	5" x 5" x 0.25" Stainless Steel Plate	1

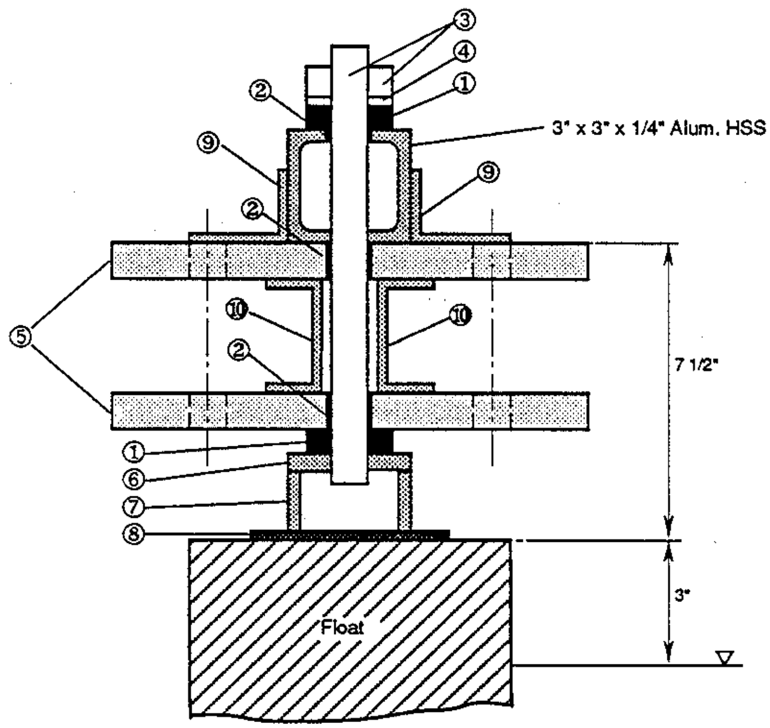
FTL	FLEET TECHNOLOGY LIMITED	
Title:	**Attachment of Float to Barrier Arm**	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922-3	Scale:
Date:		

Figure 4.5

Top View



End View



Do Not Scale

Parts List

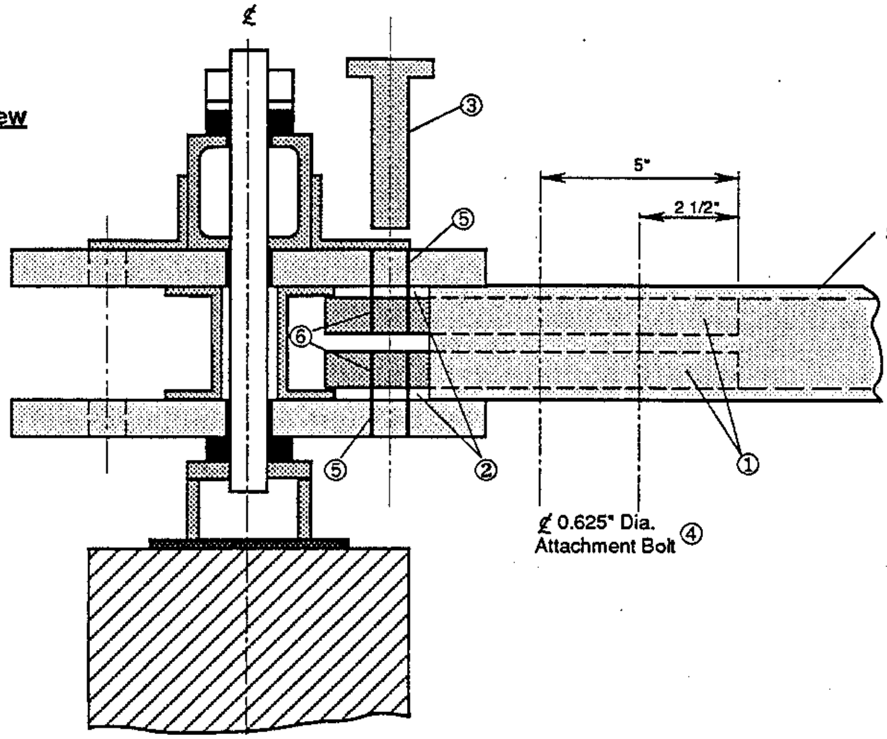
No.	Item	Qty
①	2" OD x 1" ID x 0.5" Teflon Thrust Bearing	2
②	1" ID Teflon Cylindrical Bearing	3
③	1" ID x 12" Long Stainless Steel Shaft c/w Locking Nut	1
④	2" OD x 1" ID x 0.125" Stainless Steel Washer	1
⑤	12" x 4" x 1" Stainless Steel Plate	2
⑥	3.5" OD x 1" ID x 0.5" Stainless Steel Plate	1
⑦	3" Nom. x 1.25" Long Sched. 40 Stainless Steel Pipe	1
⑧	5" x 5" x 0.25" Stainless Steel Plate	1
⑨	2" x 2" x 0.25" Aluminum Angle	2
⑩	3" x 1 1/2" x 0.25" Stainless Steel Channel	2

FLEET TECHNOLOGY LIMITED

Title:	**Apex Structure**	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922C-4	Scale:
Date:		

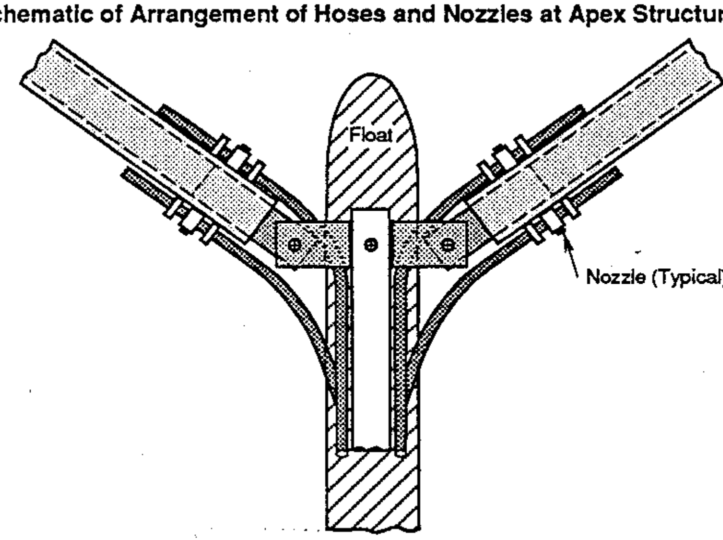
Figure 4.6

End View



Top View

Schematic of Arrangement of Hoses and Nozzles at Apex Structure



Parts List

No.	Item	Qty
①	11" x 2 1/2" x 1" Stainless Steel Plate	2
②	2" x 2" x 0.25" Stainless Steel Plate	2
③	1" Dia. x 5" Long Stainless Steel Shaft c/w Locking Nut	1
④	0.625" Dia. x 4" Long Stainless Steel Bolts	2
⑤	1" ID x 1" Long Teflon Cylindrical Bearing	2
⑤	1" ID x 1 1/4" Long Teflon Cylindrical Bearing	2

FTL **FLEET TECHNOLOGY LIMITED**

Title:	**Attachment of Apex Structure to Barrier Arms**	
Project: Project No.	Waterjet Barrier 3922C	
Dwg No.: Approved:	3922C-5	Scale:
Date:		

Figure 4.7

5.0 REFERENCES

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10. Comstock, J.P. (Ed.), Principles of Naval Architecture, The Society of Naval Architects and Marine Engineers (SNAME), New York, 1967, pp. 288-324.

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APPENDIX A:

FLOAT PERFORMANCE DATA

A.1 Float Concept Dimensions

Table A.1.1 provides the basic dimensions for the four new float concepts generated.

Table A.1.2 is a table of offsets for float LF2, the float selected for production.

A.2 Numerical Drag Estimates

Table A.2.1 gives numerical drag estimates for each float concept at zero angle of attack.

Table A.2.2 lists estimates of drag for each float concept oriented perpendicular to the direction of flow; three calculations were made for each float.

A.3 Sample Output Data from Resistance Trials

Sample output is provided for the three floats tested; designated Disk3, SF1, and LF2, for the maximum speed tested.

A.4 Presentation of Data from Resistance Trials

The statistical data calculated for each trial is provided in Table A.4.

A Note on Standard Deviation of Drag Force:

Apart from the mean resistance measurement, the standard deviation in the data was monitored closely. The towing system was initially set up and calibrated with disk float in order to get the standard deviation to an acceptable proportion of the mean. As the other two floats were tested, lower forces were measured at the equivalent speeds, and the standard deviation increased proportionally. However there was sufficient difference in the mean drag measured for each float, along with physical observations, to clearly identify float LF2 as the float with least drag.

TABLE A.1.1: FLOAT DIMENSIONS

Based on Aluminum 3X3 Box Structure
Close Form Approach: Elliptical Nose Section, Parabolic Aft body
Length of Float: L = L1+L2 ; determined by pt. of max. thickness
Beam; relate to L/B ratio
Draft : derived from Weight tables (Appendix B)
Depth of Large Float (LF'2) based on Apex Weight; Umbilical floats (LF"2)to float at lighter displacement

TABLE OF FLOAT CONFIGURATIONS

Name	x/c	Loa	L1	L2	L.P.M.	L/B	B	Awp(fwd)	Awp(aft)	Awp	T	D	Vol.	lcb
	%	(m)	(m)	(m)	(m)		(m)	(m^2)	(m^2)	(m^2)	(m)	(m)	(m^3)	(cm)
sf1	30	1	0.3	0.7	0	4	0.25	0.05891	0.1049	0.164	0.47	0.54	0.089	-13.35
sf2	40	1	0.4	0.6	0	5	0.2	0.06283	0.08	0.143	0.53	0.61	0.087	-5.97
lf1	40	2	0.4	0.6	1	10	0.2	0.06283	0.08	0.343	0.23	0.31	0.106	-54.99
lf2	30	1.63	0.3	0.7	0.625	6.5	0.25	0.05891	0.1049	0.32	0.25	0.32	0.104	-42.10
lf'2	30	1.63	0.3	0.7	0.625	6.5	0.25	0.05891	0.1049	0.32	0.48	0.55	0.177	-42.10
lf"2	30	1.63	0.3	0.7	0.625	6.5	0.25	0.05891	0.1049	0.32	0.38	0.55	0.176	-42.10

WETTED SURFACE ESTIMATE

Model	x/c	Loa	L1	L2	L.P.M.	L/B	B	Awp	T	Wetted Surface (fwd)	pm	(aft)	(total)
	%	(m)	(m)	(m)	(m)		(m)	(m^2)	(m)	(m^2)	(m^2)	(m^2)	(m^2)
sf1	30	1	0.3	0.7	0	4	0.25	0.1638	0.46	0.23	0.00	0.51	0.91
sf2	40	1	0.4	0.6	0	5	0.2	0.14283	0.52	0.34	0.00	0.50	0.98
lf1	40	2	0.4	0.6	1	10	0.2	0.34283	0.23	0.15	0.46	0.22	1.17
lf2	30	1.63	0.3	0.7	0.625	6.5	0.25	0.32005	0.24	0.12	0.30	0.27	1.02
lf'2	30	1.63	0.3	0.7	0.625	6.5	0.25	0.32005	0.47	0.24	0.59	0.52	1.67

TABLE A.1.2: OFFSETS FOR FLOAT LF2

Metric Units			Inches	
x (m)	y (m)	Y (cm)	x (in.)	y (in.)
0.00	0	0.00	0.00	0.00
0.01	0.032005	3.20	0.39	1.26
0.03	0.049957	5.00	0.98	1.97
0.05	0.069096	6.91	1.97	2.72
0.10	0.093169	9.32	3.94	3.67
0.15	0.108253	10.83	5.90	4.26
0.20	0.117851	11.79	7.87	4.64
0.25	0.123252	12.33	9.84	4.85
0.30	0.125	12.50	11.81	4.92
0.35	0.125	12.50	13.78	4.92
0.40	0.125	12.50	15.74	4.92
0.45	0.125	12.50	17.71	4.92
0.50	0.125	12.50	19.68	4.92
0.55	0.125	12.50	21.65	4.92
0.60	0.125	12.50	23.62	4.92
0.65	0.125	12.50	25.58	4.92
0.70	0.125	12.50	27.55	4.92
0.75	0.125	12.50	29.52	4.92
0.80	0.125	12.50	31.49	4.92
0.85	0.125	12.50	33.46	4.92
0.90	0.125	12.50	35.42	4.92
0.925	0.125	12.50	36.41	4.92
0.95	0.122748	12.27	37.39	4.83
1	0.118114	11.81	39.36	4.65
1.05	0.113291	11.33	41.33	4.46
1.10	0.108253	10.83	43.30	4.26
1.15	0.102969	10.30	45.26	4.05
1.2	0.097399	9.74	47.23	3.83
1.25	0.091491	9.15	49.20	3.60
1.3	0.085173	8.52	51.17	3.35
1.35	0.078348	7.83	53.14	3.08
1.4	0.070868	7.09	55.10	2.79
1.45	0.0625	6.25	57.07	2.46
1.5	0.052822	5.28	59.04	2.08
1.55	0.040916	4.09	61.01	1.61
1.575	0.033408	3.34	61.99	1.31
1.6	0.023623	2.36	62.98	0.93
1.62	0.010564	1.06	63.76	0.42
1.625	0	0.00	63.96	0.00

TABLE A.2.1: Numerical Drag Estimates for Float Concepts - Zero Angle of Attack

No Tip Correction | *Kin. Visc.= 1.14E-06 (m^2/s)*

Float No:		SF1						SF2					
V(m/s)	q	t/c	S(m^2)	Re	Cf	Cd	D(N)	t/c	S(m^2)	Re	Cf	Cd	D(N)
0.3	45.00	0.25	0.8612	2.63E+05	0.0064	0.022	0.86167	0.20	0.9263	2.63E+05	0.0064	0.017	0.722
0.5	125.00	0.25	0.8612	4.39E+05	0.0057	0.02	2.11083	0.20	0.9263	4.39E+05	0.0057	0.015	1.77
0.75	281.25	0.25	0.8612	6.58E+05	0.0051	0.018	4.32144	0.20	0.9263	6.58E+05	0.0051	0.014	3.623
1	500.00	0.25	0.8612	8.78E+05	0.0048	0.017	7.20347	0.20	0.9263	8.78E+05	0.0048	0.013	6.04
Float No:		LF1						LF2					
V(m/s)	q	t/c	S(m^2)	Re	Cf	Cd	D(N)	t/c	S(m^2)	Re	Cf	Cd	D(N)
0.3	45.00	0.10	1.1153	5.27E+05	0.0054	0.012	0.61257	0.15	0.9771	4.28E+05	0.0057	0.015	0.671
0.5	125.00	0.10	1.1153	8.78E+05	0.0048	0.011	1.51553	0.15	0.9771	7.13E+05	0.0051	0.014	1.655
0.75	281.25	0.10	1.1153	1.32E+06	0.0044	0.01	3.12465	0.15	0.9771	1.07E+06	0.0046	0.012	3.405
1	500.00	0.10	1.1153	1.76E+06	0.0042	0.009	5.23272	0.15	0.9771	1.43E+06	0.0043	0.012	5.695

Nomenclature:

D(N) = Predicted Drag in Newtons
Cd = Drag Coefficient (predicted from Hausler (1965))
Cf = Friction Coefficient from ITTC line
Re = Reynolds Number
S = Wetted Surface
t/c = thickness to chord ratio
q = 1/2 (rho) V^2

TABLE A.2.2: Numerical Drag Estimates - Float Oriented Perpendicular to Flow

				Model:	SF1							
V(m/s)	q	Cd(e)	Cd(f.p.)	Cd(Tylr.)	S(m^2)	At(m^2)	D1N)	D2(N)	Dt(N)	M1(N*m)	M2(N*m)	Mt
0.15	11.25	1.60	2.00	1.28	0.8612	0.4285	15.50	19.38	6.17	1.030457	1.28807	0.41
0.3	45.00	1.60	2.00	1.28	0.8612	0.4285	62.01	77.51	24.68	4.121829	5.15229	1.641
0.5	125.00	1.60	2.00	1.28	0.8612	0.4285	172.24	215.30	68.56	11.44952	14.3119	4.558
0.75	281.25	1.60	2.00	1.28	0.8612	0.4285	387.53	484.42	154.26	25.76143	32.2018	10.25
1	500.00	1.60	2.00	1.28	0.8612	0.4285	688.95	861.18	274.24	45.7981	57.2476	18.23
				Model:	SF2							
V(m/s)	q	Cd(e)	Cd(f.p.)	Cd(Tylr.)	S(m^2)	At(m^2)	D1N)	D2(N)	Dt(N)	M1(N*m)	M2(N*m)	Mt
0.15	11.25	1.60	2.00	1.28	0.9263	0.4887	16.67	20.84	7.04	0.671212	0.83901	0.283
0.3	45.00	1.60	2.00	1.28	0.9263	0.4887	66.69	83.37	28.15	2.684848	3.35606	1.133
0.5	125.00	1.60	2.00	1.28	0.9263	0.4887	185.26	231.58	78.19	7.45791	9.32239	3.148
0.75	281.25	1.60	2.00	1.28	0.9263	0.4887	416.84	521.05	175.94	16.7803	20.9754	7.083
1	500.00	1.60	2.00	1.28	0.9263	0.4887	741.05	926.31	312.78	29.83164	37.2895	12.59
				Model:	LF1							
V(m/s)	q	Cd(e)	Cd(f.p.)	Cd(Tylr.)	S(m^2)	At(m^2)	D1N)	D2(N)	Dt(N)	M1(N*m)	M2(N*m)	Mt
0.15	11.25	1.60	2.00	1.28	1.1153	0.4288	20.08	25.09	6.17	1.005203	1.2565	0.309
0.3	45.00	1.60	2.00	1.28	1.1153	0.4288	80.30	100.38	24.70	4.020811	5.02601	1.237
0.5	125.00	1.60	2.00	1.28	1.1153	0.4288	223.06	278.83	68.61	11.16892	13.9612	3.435
0.75	281.25	1.60	2.00	1.28	1.1153	0.4288	501.89	627.36	154.36	25.13007	31.4126	7.729
1	500.00	1.60	2.00	1.28	1.1153	0.4288	892.25	1115.31	274.42	44.67568	55.8446	13.74
				Model:	LF2							
V(m/s)	q	Cd(e)	Cd(f.p.)	Cd(Tylr.)	S(m^2)	At(m^2)	D1N)	D2(N)	Dt(N)	M1(N*m)	M2(N*m)	Mt
0.15	11.25	1.60	2.00	1.28	0.9263	0.4887	16.67	20.84	7.04	1.525711	1.90714	0.644
0.3	45.00	1.60	2.00	1.28	0.9263	0.4887	66.69	83.37	28.15	6.102845	7.62856	2.576
0.5	125.00	1.60	2.00	1.28	0.9263	0.4887	185.26	231.58	78.19	16.95235	21.1904	7.155
0.75	281.25	1.60	2.00	1.28	0.9263	0.4887	416.84	521.05	175.94	38.14278	47.6785	16.1
1	500.00	1.60	2.00	1.28	0.9263	0.4887	741.05	926.31	312.78	67.80939	84.7617	28.62

Nomenclature:

Cd(e) = Drag Coeff. form Hausler (1965) for ellipse; associated drag = D1
Cd(f.p.) = Drag Coeff. form Hausler (1965) for flat plate; associated drag = D2
Cd(Tylr) = Drag Coeff. form PNA (1967) based on projected area; assoc. drag= Dt
S = Wetted Surface q = 1/2 (rho) V^2
Af = Frontal Area

STATISTICS SUMMARY

SAMPLE OUTPUT: DISK FLOAT

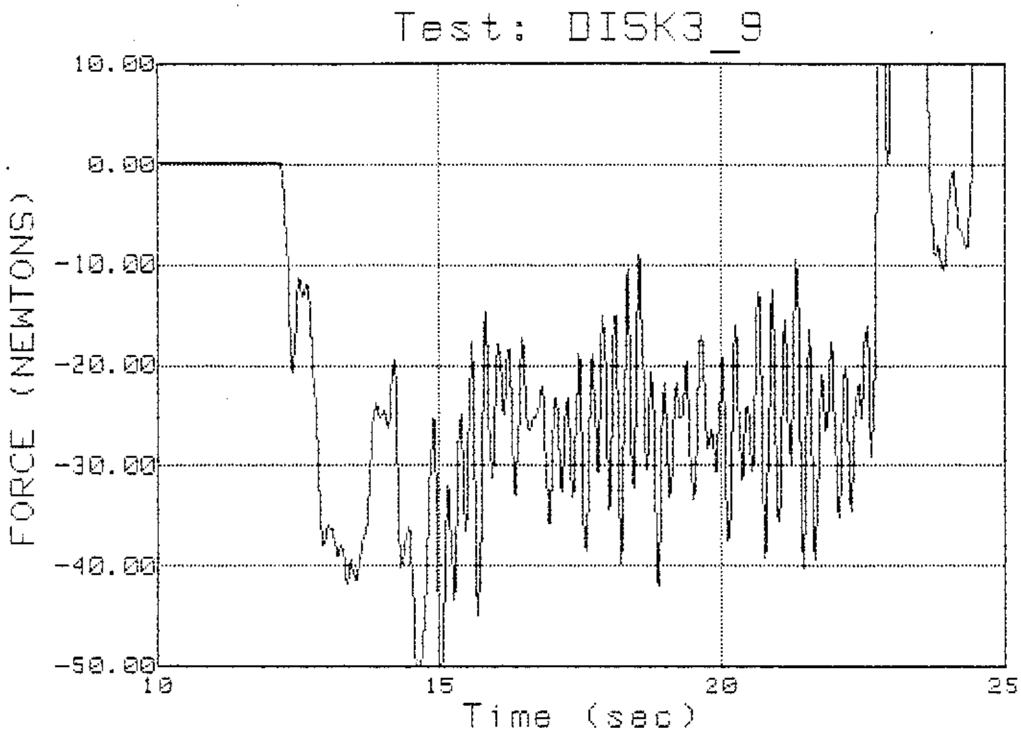
STATISTICS SUMMARY

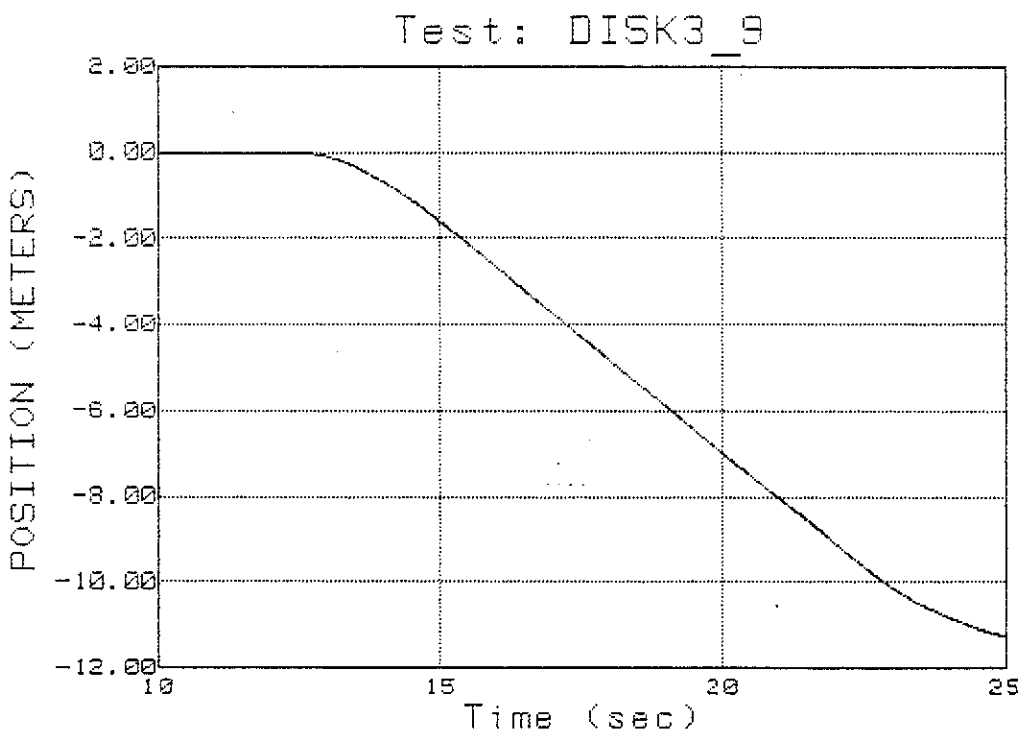
Project Number 3922
WATERJET BARRIER

Test Name:	DISK3_9
Date:	4 Feb 1991
Start Time:	14:50:11
Scanning Rate	50 Hz
Test Duration	40.0000 seconds

Interval 1 beginning at: 16.8800 seconds
Interval 1 ending at: 22.1800 seconds

CHANNEL	NAME	UNITS	MAXIMUM	MINIMUM	MEAN	STD DEVIATION
1	FORCE	NEWTONS	-9.146	-41.995	-25.950	6.976
2	POSITION	METERS	-3.6424	-9.3132	-6.4712	1.6468


Test: DISK3_9
FORCE (NEWTONS)
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
10
15
20
25
Time (sec)


Test: DISK3_9
POSITION (METERS)
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
10
15
20
25
Time (sec)

STATISTICS SUMMARY

FLOAT SF1: AIRFOIL

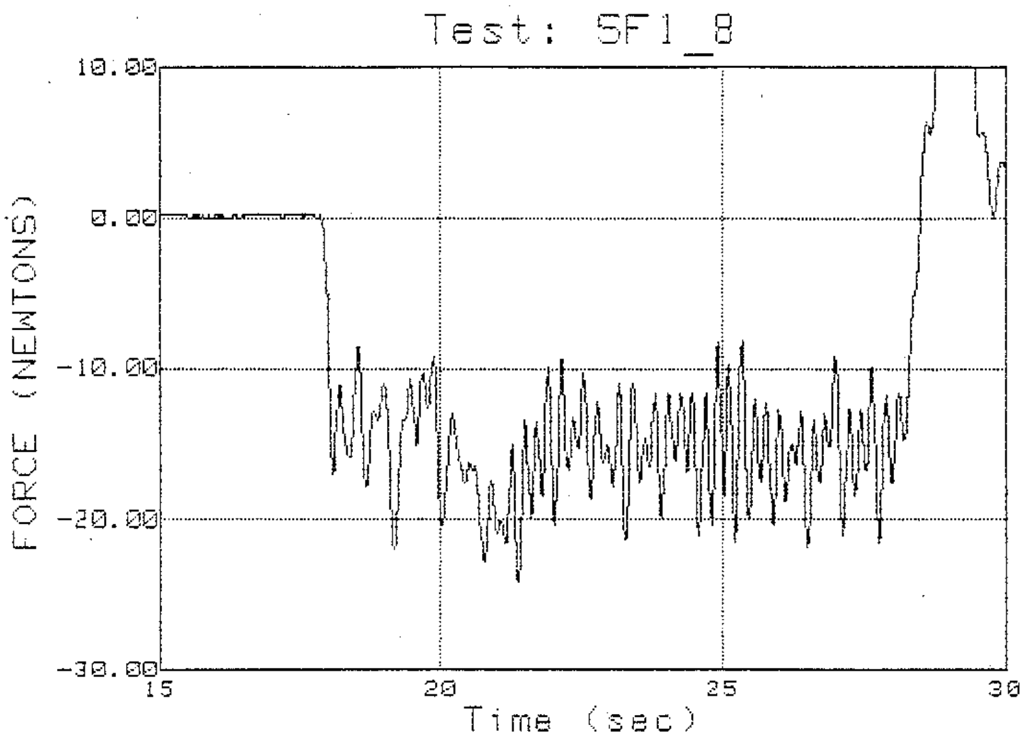
STATISTICS SUMMARY

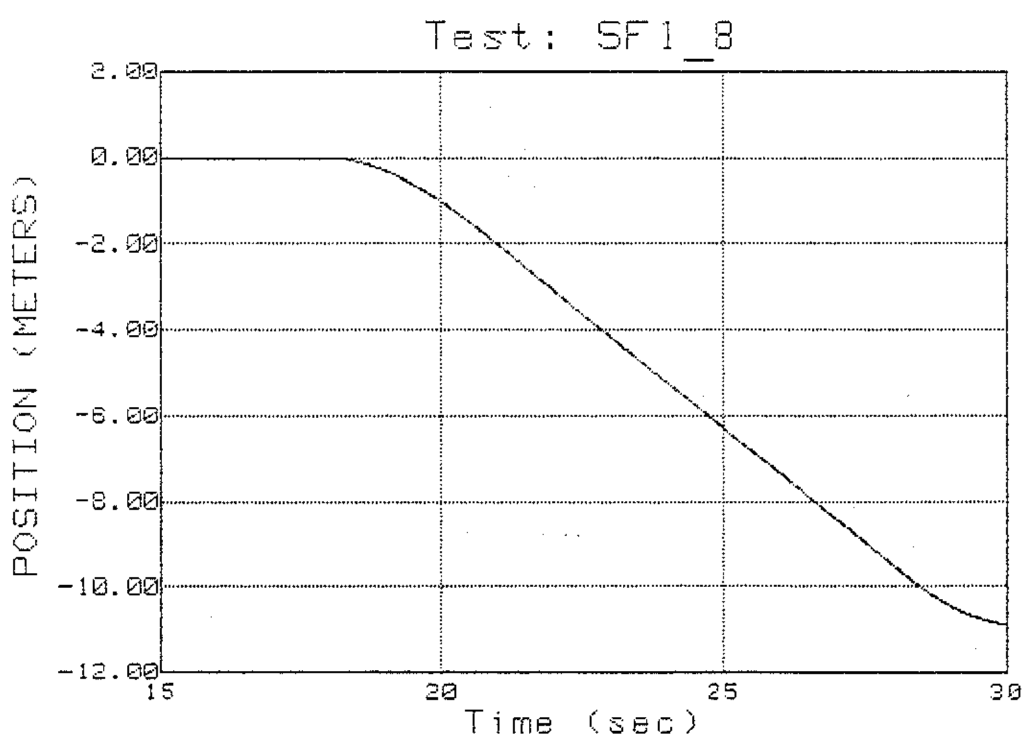
Project Number 3922
WATERJET BARRIER

Test Name:	SF1_8
Date:	6 Feb 1991
Start Time:	10:13:43
Scanning Rate	50 Hz
Test Duration	60.0000 seconds

Interval 1 beginning at: 21.9000 seconds
Interval 1 ending at: 27.6800 seconds

CHANNEL	NAME	UNITS	MAXIMUM	MINIMUM	MEAN	STD DEVIATION
1	FORCE	NEWTONS	-8.185	-21.768	-15.141	2.973
2	POSITION	METERS	-2.9831	-9.1655	-6.0726	1.7906


Test: SF1_8
FORCE (NEWTONS)
10.00
0.00
-10.00
-20.00
-30.00
15
20
25
30
Time (sec)


Test: SF1_8
POSITION (METERS)
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
15
20
25
30
Time (sec)

STATISTICS SUMMARY

FLOAT LF2: BOAT HULL

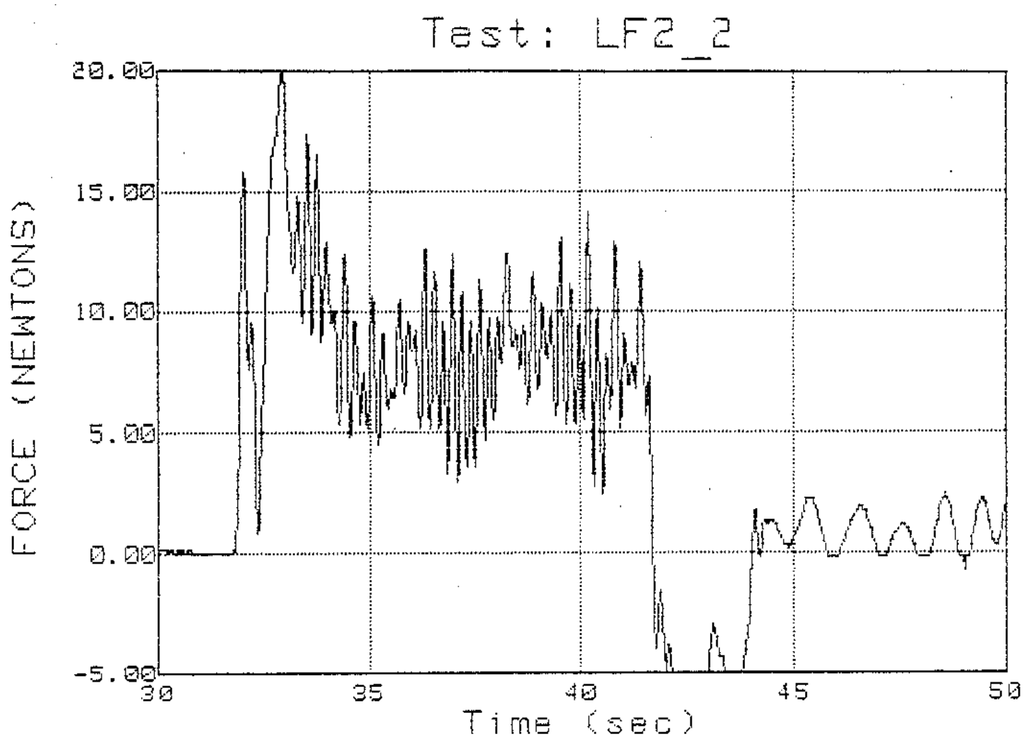
STATISTICS SUMMARY

Project Number 3922
WATERJET BARRIER

Test Name:	LF2_2
Date:	8 Feb 1991
Start Time:	15:49:59
Scanning Rate	50 Hz
Test Duration	60.0000 seconds

Interval 1 beginning at: 36.0600 seconds
Interval 1 ending at: 41.0400 seconds

CHANNEL	NAME	UNITS	MAXIMUM	MINIMUM	MEAN	STD DEVIATION
1	FORCE	NEWTONS	14.106	2.438	8.162	2.427
2	POSITION	METERS	-3.5199	-8.8268	-6.1730	1.5445


Test: LF2_2
FORCE (NEWTONS)
20.00
15.00
10.00
5.00
0.00
-5.00
30
35
40
45
50
Time (sec)

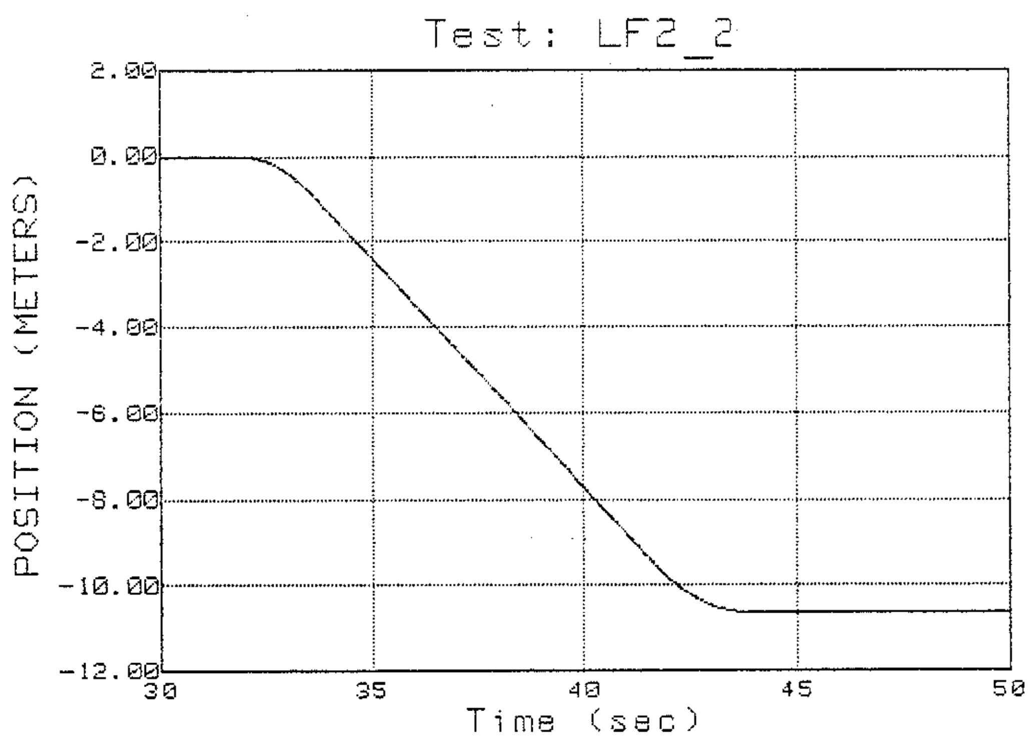

Test: LF2_2
POSITION (METERS)
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
30
35
40
45
50
Time (sec)

TABLE A.4: Summary of Experimental Resistance Results for Waterjet Floats

	Model:	*Disk*		*SF1*		*LF2*	
		Mean	Std.	Mean	Std.	Mean	Std.
V(knots)	V (m/s)	Rm(N)	Deviation	Rm(N)	Deviation	Rm(N)	Deviation
0.58	0.3	2.2391	1.463	0.689	0.7471	0.6506	0.4402
0.58	0.3	2.3418	1.4041	-	-	0.5265	0.4837
0.97	0.5	6.375	2.567	2.0869	1.0285	1.0785	0.7821
0.97	0.5	6.382	2.508	1.9151	1.0052	1.0392	0.8287
1.36	0.7	12.246	3.42	4.5498	1.6209	1.9985	1.1893
1.36	0.7	12.35	3.637	4.6376	1.6213	2.3818	1.2172
1.55	0.8	-	-	6.803	1.545	3.7254	1.3167
1.55	0.8	-	-	7.142	1.576	3.3456	1.2321
1.75	0.9	-	-	11.407	2.39	5.844	1.624
1.75	0.9	-	-	11.313	2.357	7.579	2.503
1.94	1	25.253	7.007	15.117	2.906	9.16	2.246
1.94	1	25.453	6.9	15.141	2.973	8.162	2..427

Note: Velocities are nominal based on Speed Control Setting

B. Measured Thrust Developed By Waterjet:

1) At 500 psi: Thrust = 62.4 N

2) At 1000 psi: Thrust = 106.4 N

APPENDIX B:

WEIGHT ESTIMATES

FOR

WATERJET BARRIER COMPONENTS

TABLE B.1.1: WEIGHT / BUOYANCY TABLE FOR "FTL WATER JET BARRIER" ARM

Best Estimated Weights ; 20/2/91

Item	Qty.	Len (cm)	Dia (cm)	Width (cm)	Ht (cm)	Density (kg/m^3)	Area (cm^2)	Vol (cm^3)	Wt. (kg)	WT(lbs) (in)
Hose & Swivel		147.3	5.45						*7.45*	
Nozzle & cnctr									*0.75*	
Tee		;(7.1)		7.1					*0.95*	
Hose Units [Wet]	2	243.4		10	5				32.87	
Box Structure	1	275		7.62	7.62				11.80	26
Box Connector	1.5								2.04	4.5
Mounting Plate	1								1.09	2.4
Pin/Sleeve Unit	1								2.22	4.9
Mounting Straps	2								0.54	1.2
Bolts	12								2.27	5
Skeg Plate	1			3/16"		.1 lb/in3	291.6in2	54.7	2.50	5.5
Skeg brackets	2	36"		1/8"	2X2"	.561 lbs/ft.			0.77	1.7
Sub-total									56.10	
Margin (%)									5	
TOTAL UNIT									59	

TABLE B.1.2: WEIGHT TABLE FOR WATER JET BARRIER UMBILICAL STRUCTURE

Best Estimated Weights ; 20/2/91

Item	Qty.	Len (cm)	Dia (cm)	Width (cm)	Ht (cm)	Density (kg/m^3)	Area (cm^2)	Vol (cm^3)	Wt. (kg)	WT(lbs)
Hose & Swivel		147.3	5.45						*7.45*	
Nozzle & cnctr									*0.75*	
Tee		;(7.1)		7.1					*0.95*	
Hose Units [Wet]	2	243.4		10	5				65.75	
Box Structure	1	275		7.62	7.62				11.80	26
Box Connector	1.5								2.04	4.5
Mounting Plate	1								1.09	2.4
Pin/Sleeve Unit	1								2.22	4.9
Mounting Straps	2								0.54	1.2
Bolts	12								2.27	5
Skeg Plate	1			3/16"		.1 lb/in3	291.6in2	54.7	2.50	5.5
Skeg brackets	2	36"		1/8"	2X2"	.561 lbs/ft.			0.77	1.7
Sub-total									88.98	
Margin (%)									5%	
TOTAL UNIT									93	

At Apex - Displacement :		= Wt. of Barrier Unit + 0.5xUmbiliical Wt. + Increment Wt. Apex Structure
		; = 59 kg + 0.5*93 kg + 12 kg
		; = 118 kg

DIfference in Displacement in Umbilical Floats	: = 118 kg -93 kg
	:= 25 kg